NATO III Satellite Communications System Control

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The system control concepts to improve channel utilization and the recent progress of the design, development, and integration of the control subsystem for the satellite communications network are reported. The network operates with a large number of single-destination radio frequency carriers to provide voice, low-speed telegraph, and medium-speed data circuits. A power control algorithm to keep the link quality at the desired nominal level and a traffic control algorithm allowing reconfiguration of the network to accommodate fluctuating traffic are presented. The system control software development cycle, consisting of design, which includes functional decomposition and software module structure, integration and testing phases, is discussed. Various functional flow diagrams are provided illustrating the information interfaces to external communications, the network data base, and the physical devices. An example illustrating the performance of power control and traffic control software is presented.

Introduction

IN 1970, the North Atlantic Treaty Organization (NATO) Defense Ministers approved a program to develop a common-user communication system called the NATO Integrated Communications System (NICS). The aim of the NICS is to provide communications between eligible military and civil authorities of NATO during peacetime, as well as during potential periods of stress or conflict. The development has been divided into a two-stage program. NICS Stage I (1975-1985) includes the procurement and implementation of separate voice and telegraph switching networks along with improvements and additions to NATO-owned transmission subsystems such as the Satellite Communications System. NICS Stage II (post-1985) comprises the progressive expansion and integration of the major subsystems, including the eventual conversion to all-digital operation.[1,2]

The design phase of the NATO III Satellite Communications System has been completed recently and the equipment is now being manufactured.[3] The new system will be completed in mid-1983 and will consist of two system control centers (SCCs), 12 existing static satellite ground terminals (SGTs) modified to satellite communications standards, 9 new static SGTs, and 2 new transportable SGTs. The new system will use over 200 single-destination QPSK carriers and will provide some 500 voice, 400 low-speed telegraph, and 200 medium-speed data circuits by the use of time-division multiplex (TDM) equipment.

The control facilities being built into the SATCOM III facilities have the following basic objectives[4,5]:

1) Centralized control of each carrier power.
2) Central control of circuits through link capacity management.
3) Centralized monitoring of network status.

This paper deals with the design and implementation of the control subsystem of the SATCOM III system.

System Control Concept

A satellite in orbit represents a fixed channel capacity in terms of power and bandwidth for carrying traffic. Consequently, the problem is to maximize user traffic that is transmitted through the in-orbit capacity.

The control subsystem is designed to deal with changing traffic and transponder loading because of the change in requirements and/or transmission properties. The system parameters, which may be controlled by the subsystem, are total transmit power for each SGT,transmit power for all carries, number of channels per carrier in use, and bit rate of each carrier.

In order to control these parameters properly, a number of system characteristics are measured and correlated. These characteristics are received signal quality per carrier (BER), receiver noise temperature, signal bandwidth, signal frequency, satellite total transponder transmit power, received satellite beacon power at each ground terminal, beacon telemetry, and ground terminal equipment status.

The control system collects information automatically and periodically from each of the SATCOM terminals, compares this information to that in a data base maintained in the computer, and generates appropriate commands to control the parameters listed previously. There is a need for operator-entered commands, e.g., data base update; however, the system is automated to the extent practical.

System Control Centers

The SCC consists of two geographically separated identical control centers, the Master Control Center (MCC), and the Alternate Control Center (ACC), which receive all status and performance data from every transmitting SGT in the network. Figure 1 is a pictorial overview of the SCCs and SGTs. Each control center is capable at all times of performing monitoring and control functions for all SGTs in the network. SCCs communicate with SGTs over satellite links and with each other over terrestrial communications links. During normal operation one SCC operates in an active (command) mode while the other operates in a standby mode, thereby

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increasing the survivability measure enormously. Since all SCCs receive identical status and performance data from every SGT in the network, the dynamic status and performance data bases at each SCC are identical and, within the limits of communications delays, are synchronized. The standby SCC, through the inter-SCC link, can function as a backup link between the active SCC and an SGT when the direct (satellite) link between the active SCC and the SGT has failed. Figure 2 shows the basic block diagrams of the control center and their interface with the collocated SGT.

Major components of the SCC are:

1) SCC processor (Minicomputer HP-2113E).
2) Main memory, 512 Kbytes.
3) Mass storage, redundant 19.6 Mbytes disk.
4) Operator terminal consisting of a color CRT and keyboard.
5) Printer/plotter.
6) Automatic spectrum analyzer (ASPAN).
7) Signal generator.
8) Power meter.
9) Automatic data reporting system (ADRS) concentrator.
10) Control processor.

Each SCC receives equipment status and link performance data from every SGT in the network at the rate of one frame every 2 s. Similarly, each SCC transmits power control and link configuration data to every SGT in the network at one frame every 2 s. Both incoming and outgoing frames are transmitted by their source twice (a rate of one frame per 4 s). Upon arrival, each pair of frames is compared in order to detect transmission errors.

SCC link algorithms use data originating at transmit SGTs, at the satellite, or at the SCC itself. Telemetry data from the satellite are monitored at the SCC to determine actual transponder utilization aboard the satellite. Uplink power levels, E_m/N_0, and received beacon power levels monitored at each SGT are reported to the SCC.

Each SCC generates command to control the total transmit power at each SGT, based on reported and calculated parameters that include operating noise temperature (ONT), carrier power-to-terminal noise density ratio (C/kT), and the energy per bit-to-thermal noise density ratio (E_m/N_0). ONT calculation is based on measured data from ASPAN, as is C/kT. Transponder utilization is based on telemetry data from the satellite or (if telemetry data is not available) on uplink transmitted carrier powers reported from the SGTs.

The SCC controls the configuration of time-division multiplexers (MUXs) and QPSK modems at each SGT by downloading configuration data over the satellite link. The network planning function of the SCC allows the network controller to analyze the satellite transponder power required to support a new configuration prior to initiating a traffic configuration change. The algorithm used for new configuration transponder utilization is similar to that used for power control, but is influenced by actual SGT hardware or satellite transponder limitations. These limitations are displayed to the operator for comparison purposes.

Centralized network control is performed automatically by the SCC, with network planning, data base management, and status or performance reporting being carried out by the operator through an interactive man-machine interface (MMI).

The microprocessor-based front-end processors, the ADRS concentrator and the control processor, are designed to share the workload of the minicomputer and provide greater flexibility in the total system design. The ADRS concentrator works as a pipeline processor. It receives commands from the control center and distributes them to the ground terminals. Conversely, all status and responses from the ground terminals are funneled through the concentrator to the control center. The control processor resides inside the ground terminals, relays the ADRS data flow, and monitors the status of the baseband equipment (TDMs and modems). Upon receiving command from the ground terminal, the control processor informs the baseband equipment to switch in/out end-user circuits.

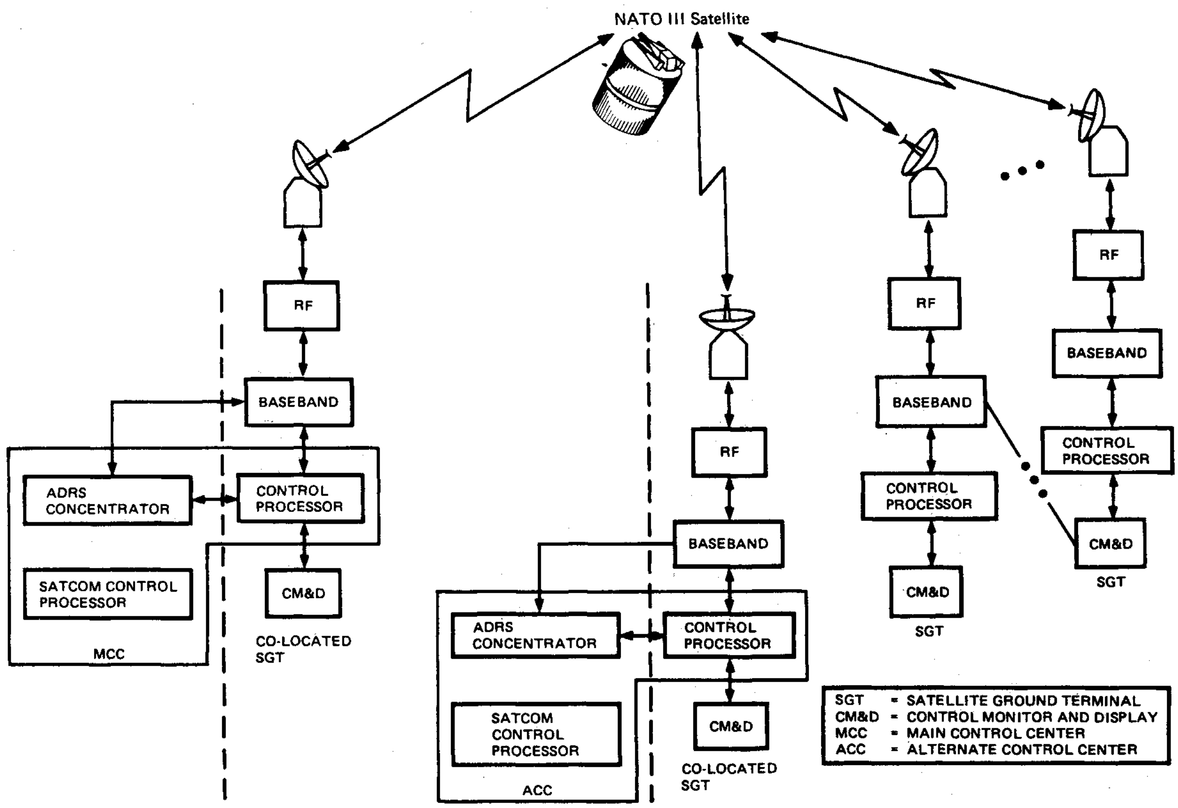

Fig. 1 System control configuration.

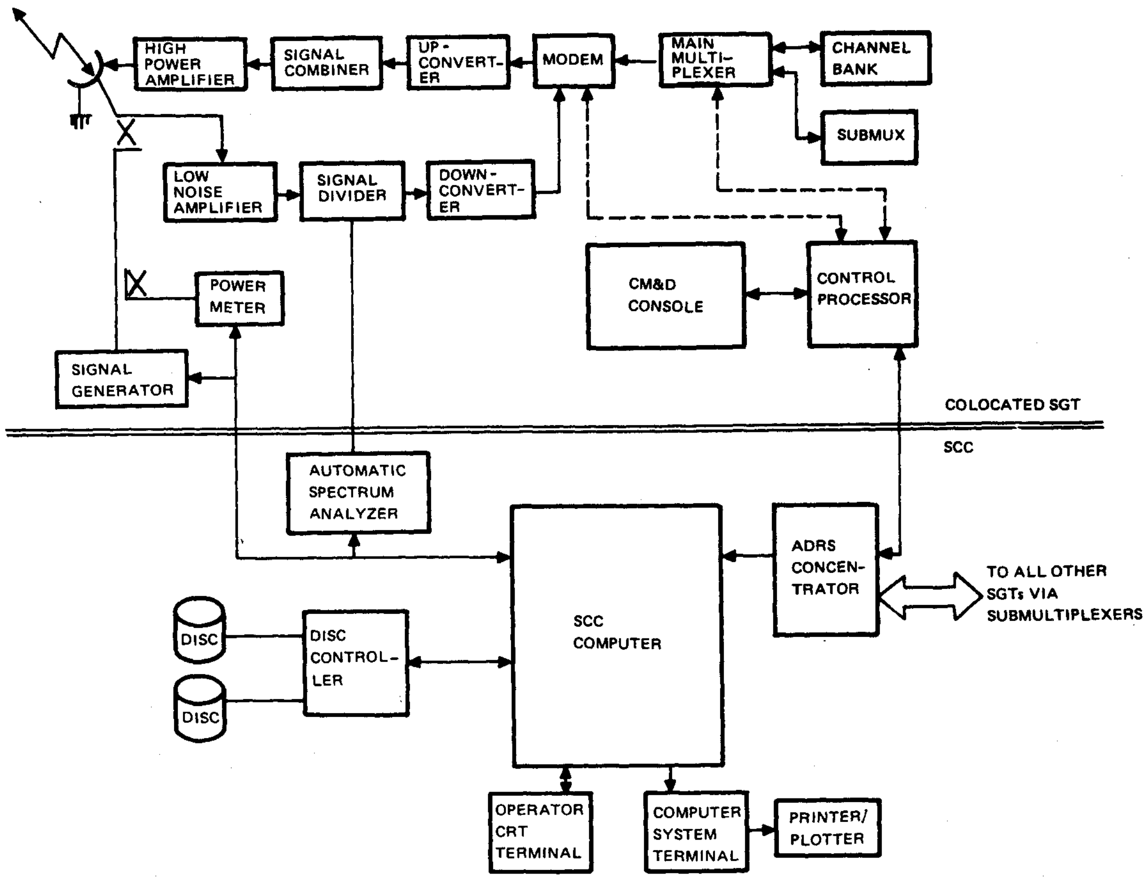

Fig. 2 SCC block diagram.

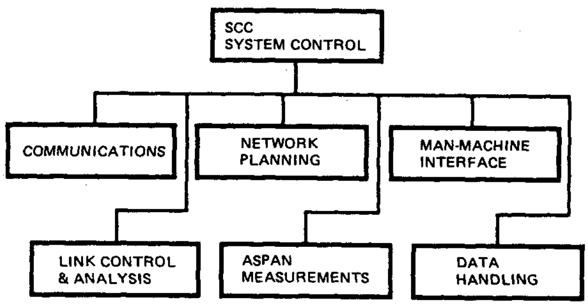

Fig. 3 Top-level functional decomposition.

Satellite Ground Terminals and Command, Monitor, and Display Subsystem

A typical static SGT includes the following equipment categories: power equipment, link equipment, control facilities, beacon receiver, test facilities, test equipment, and ancillary equipment.

The heart of the control facilities is the automated command, monitor, and display subsystem (CM&D). The CM&D subsystem monitors and displays numerous parameters of the SGT and provides commands to the several variable components of the SGT equipment in order to achieve an optimum and efficient operation of the SGTs. Command and control of the SGT equipment may be achieved locally from the CM&D subsystem or from the system control center (s). The CM&D subsystem monitors and displays:

1) Antenna movement and position (elevation and azimuth angles).
2) Ephemeris data for the previous 24 h.
3) Receiver performance (gain, noise temperature).
4) Path loss variations (beacon signal strength).
5) Beacon information (identification).
6) Performance of each received carrier (E_m/N_0).
7) Power level of each transmitted carrier.
8) Total power level of the transmitter.

All data and status information mentioned above are collected at the CM&D, put into message format, and then transmitted to the SCC. Similarly, the command messages received from the SCC are sorted at the CM&D and directed to the relevent equipment for execution. The CM&D subsystem is a focal point of an SGT for the SCC.

Power Control and Traffic Control

The control subsystem provides both uplink transmit carrier power control and network traffic control and is applicable to single-destination digitally modulated carriers. The power control algorithm is based on the maintenance of the bit error rate within prescribed limits for each link.

The power control algorithm utilizes the measured received power level, E_m/N_0, for QPSK carriers, and received beacon level for all the non-QPSK carriers to calculate the individual uplink carrier power level. These data are reported to the control center by all SGTs through the ADRS. By comparing the calculated power level with a desired level, power changes of individual carrier can be derived.

Before the power change command is transmitted, the control center ensures that the change in link quality is not due to ground terminal equipment failure and that both the ground terminal HPA and the satellite transponder have sufficient power reserved for the change. These are determined from the reported equipment status, beacon level, and telemetry data.

In order to prevent system oscillation, power control must use the E_m/N_0 measured after the receive power level has changed to determine the next transmit power level setting. Therefore, the performance of power control is highly dic-

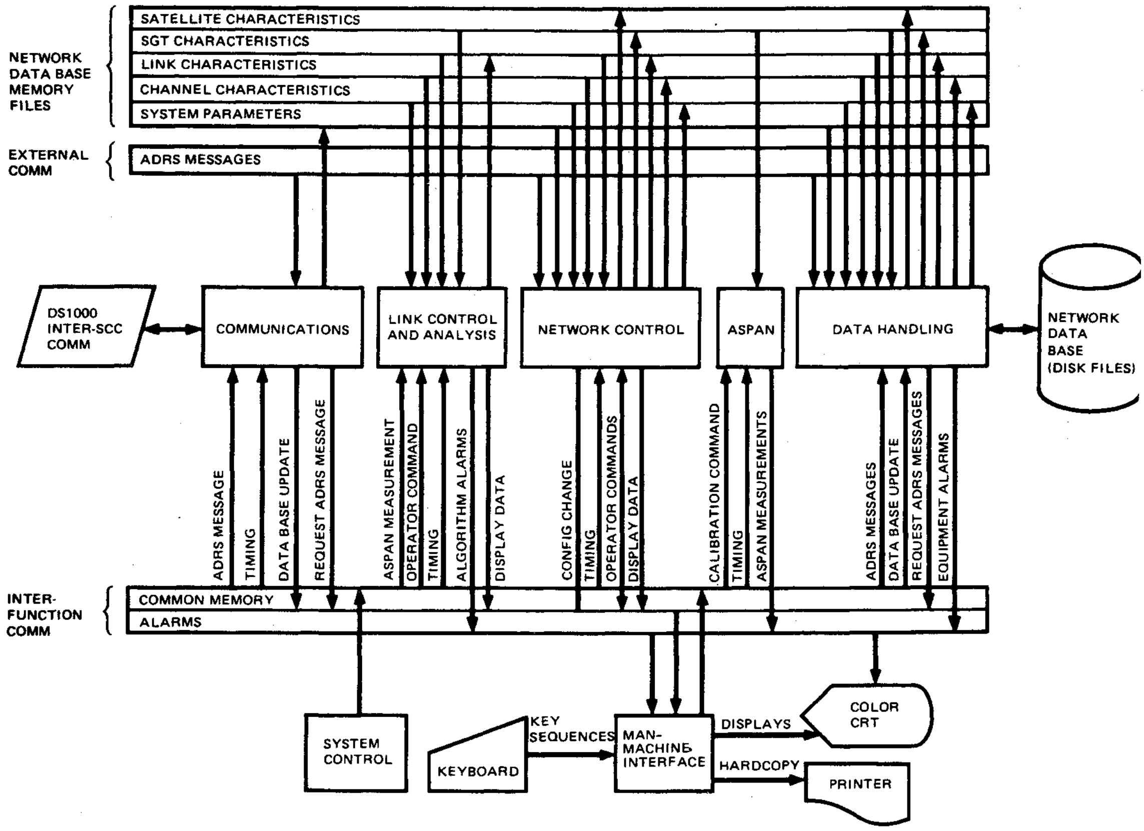

Fig. 4 SCC overall information flow.

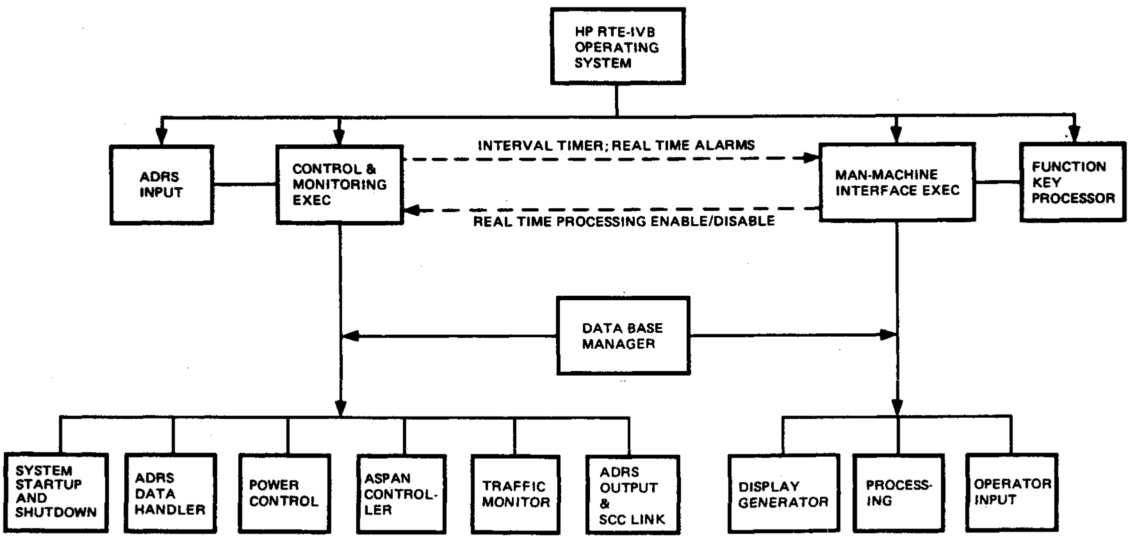

Fig. 5 Module structure.

tated by a relatively long control loop time constant and the power change command can occur only once per control loop. It has been shown[5] that a 16-s control cycle results in a 3 dB gain of the satellite capacity.

To control traffic a number of traffic configurations are stored at each ground terminal. In each traffic configuration the number of voice and data channels in each carrier is specified. The control center can issue commands to the ground terminals to switch to any prestored configuration at a specified time. This capability allows reconfiguration of the network to accommodate traffic pattern changes such as traffic demand variations related to time of day, time zone differentials, or changes in communications environment.

Traffic control and power control are coupled in the sense that a network reconfiguration automatically results in a resetting of the individual carrier powers and the total transmit power.

System Software Design

The overall control subsystem software development process includes top-level and detailed design, coding, integration, and testing phases. Top-level design consists of forming 1) functional decomposition and 2) a software module structure. The requirements described in the preceding System Control Concept section are decomposed in a top-down functional manner. The software structure is

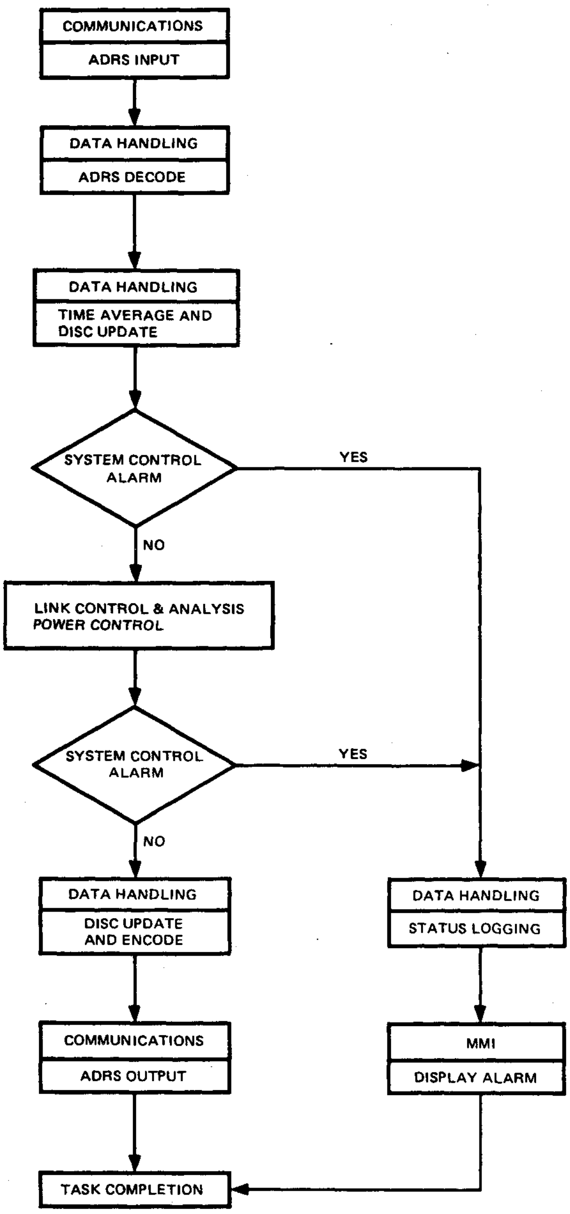

Fig. 6 Functional flow—power control.

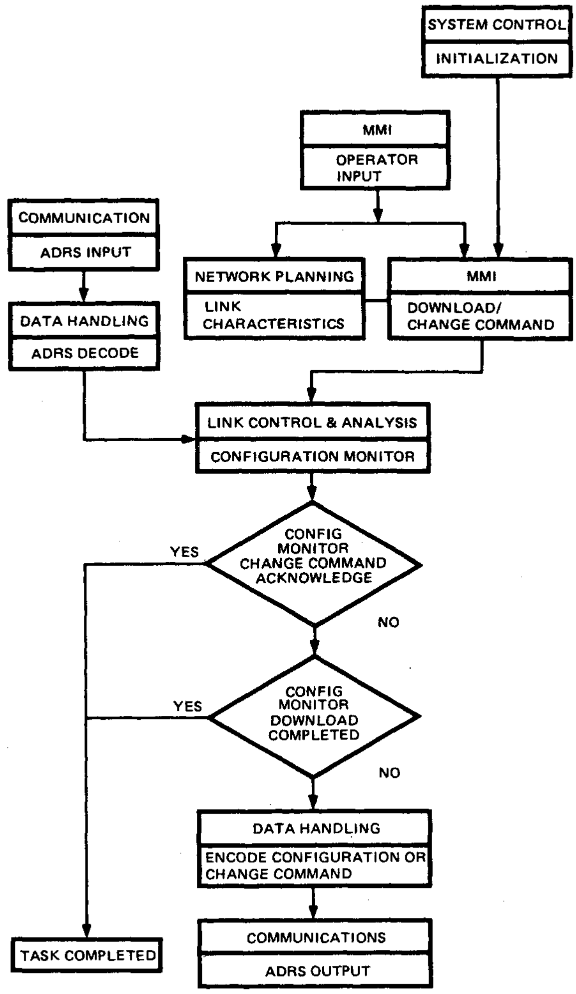

Fig. 7 Functional flow—traffic control.

designed in a modular fashion establishing the task performance and specifying interfaces. At the next level, the detailed design includes the implementation decisions, algorithm, and data representations. Coding translates the detailed design into the implementation language, e.g., FORTRAN.

Functional Decomposition

The subsystem requirements are broken down conceptually into the following functions and are illustrated in Fig. 3.

System Control

System control consists of subfunctions that control the initialization/shutdown, scheduling, and timing of the entire control subsystem. It includes a system executive that schedules program modules for execution, ensures that power control is performed within the required time frame, ensures that C/kT measurements are performed for the required number of downlink carriers within the correct time frame and synchronizes transfer of control (active/standby) between the SCCs. It also provides the capability for a cold or warm start initialization of the data base, control parameters, and communications links, and orderly system shutdown.

Communications

The communications function provides input/output for receiving or transmitting ADRS messages, for receiving telemetry messages, and for establishing communications with the other SCC via the inter-SCC ground communication link.

Link Control and Analysis

Power control, C/kT, and operating noise temperature calculations are performed by link control and analysis. This function also decides if an unauthorized carrier does exist, monitors the current operating traffic configuration, and projects transponder utilization when a new traffic configuration would be implemented.

Network Planning

Network planning provides the operator with the ability to enter and update the data base parameters, e.g., satellite, SGT, and link characteristics.

Automatic Spectrum Analyzer (ASPAN) Measurement

The automatic spectrum analyzer (ASPAN) measurement function controls the HP 8566 Automatic Spectrum Analyzer and receives measured data from the ASPAN. This includes control of C/kT measurement, ONT measurement, and the scan of the frequency spectrum to detect the presence of unauthorized carriers.

Man-Machine Interface

Man-machine interface consists of software to decode operator keyboard inputs and to produce displays from these inputs as well as calculated results and data base parameters.

Data Handling

Data handling contains the data base manager, which is used to generate and update the data base. It is also responsible for ADRS message encoding/decoding, time-averaging of status data, and logging of selected status data and alarms.

The overall information flow within the SCC software is represented in Fig. 4. The diagram shows four types of information interface: external communications, interfunction communications, the network data base in memory, and the physical devices. Most of these interfaces are depicted by horizontal bands that can be thought of as buses onto which the functions place information and from which others retrieve information. The information at the interface is noted inside each band and the type of interface is noted at the left of the bands. An exception is made in the case of common memory where the varied types of information are identified on the vertical lines that indicated the interface. The physical devices (DS-1000, disk, operator console keyboard, operator console color CRT, and printer) are depicted graphically.

Software Module Structure

Functional decomposition defines the major functions of the control subsystem. When these functions are defined further so that they are no longer divisible, the result is the software module structure. This is a hierarchical structure starting from the top (the major functions) down to a set of functional entities called modules. Figure 5 shows the modular structure.

The Hewlett Packard RTE IV B operating system is included in the structure to demonstrate that a multitasking operating system is required in this application.

Power and Traffic Control Example

To demonstrate how the SCC software modules are interfaced, consider the following two events that occur concurrently: The continuous monitoring and control of the uplink power, and an operator intervention, e.g., a command to broadcast a new traffic configuration.

The functional flow of tasks to complete the two events is illustrated in Figs. 6 and 7. The ADRS input is a continuous incoming data stream (at a rate of 600 bits/s/SGT). The communications and data handling functions must be active at all times to receive and parse the information. This information is later used by other modules which, in this case, are power control and configuration monitor. Meanwhile, the operator may, through the man-machine interface, enter a new traffic configuration into the link characteristics data base. After careful examination, the data entries are displayed on the color console (blinking red asterisks are shown preceding the data entries that do not pass the sanity check of MMI). The operator may proceed to command a configuration download to take place. A hard copy of the new traffic configuration is provided as a permanent record. In this example, the power control block in Fig. 6 is elaborated on the flow diagram shown in Fig. 8.

The power control algorithm, implemented with a 16-s time constant, allows for a 3 dB reduction in link margins. The traffic control algorithms allow reconfiguration of the network to accommodate fluctuating traffic patterns related to time of day, time zone differentials, or to changes in the communications environment.

Thus, the dynamic response of the central-controlled network to fluctuating demands precludes the requirement for sizing permanent and costly facilities to meet localized low duty cycle demand occurrence.

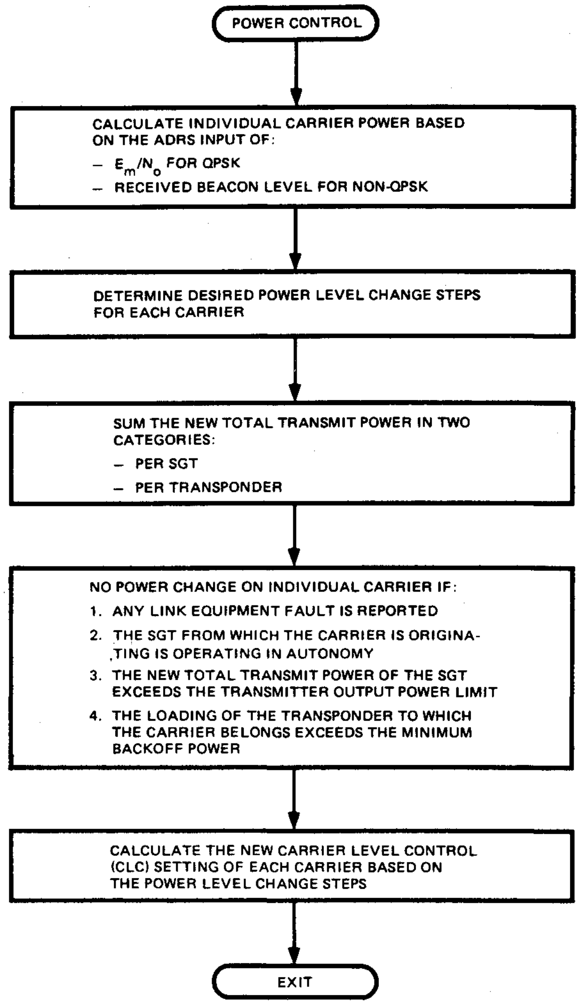

Fig. 8 Power control flowchart.

The power control algorithm computation needs to be completed within 1 s so that the 16-s control loop time constant can be maintained. As revealed in the flow diagram (Fig. 8), the computation must cycle through 200 QPSK carriers, 21 SGTs, 2 transponders, and an enormous amount of equipment status checking before new carrier-level control settings are determined. The SCC computer may reach the "CPU utilization" limit during that critical second. Two parallel paths were taken to analyze the problem. A computer model was used with the assumption that ADRS input and some but limited disk access are taking place concurrently. The result shows a 79% utilization. In addition to the computer model analysis, the power control algorithm actually was coded and run on the computer. The CPU execution time was 750 ms.

System Integration and Testing

Upon completion of the coding process each module is subjected to testing by executing the module test procedure. The functional requirements allocated to the modules are validated by this procedure. The testing process begins with the top-level module and one lower level of modules. Modules below this level are replaced by "stubs" – dummy routines that are used to take the place of a missing lower-level module during the checkout process. Each stub performs two functions. First, a stub must return a result that will allow meaningful execution of the calling module to continue. It is usually sufficient for the stub to return set constants for output although it may be necessary at times for the stub to return set constants for output although it may be necessary at times for the stub to solicit information from the operator or to obtain its results from a script file. Second, a stub may print pertinent information to aid the evaluation of the software's performance. For example, the stub may print a message stating who called the stub and what the inputs and outputs were. After this skeleton of the software is tested to determine that the major interfaces are working correctly, another level of logic is added. This procedure continues until the entire system is tested and integrated, one level at a time.

The term "top-down testing" may be somewhat misleading if taken too literally. The top-down testing approach makes two demands. The modules are tested in an order that eliminates (or more practically, minimizes) testing any module whose testing is dependent on other modules not yet implemented or on data that is not yet available; and higher-level modules are used to drive the lower-level modules during testing. The advantages of top-down testing are:

1) It is much easier to find bugs using the top-down approach as the location if the bug is limited to the module being tested.

2) Top-down testing provides a natural "test harness" for the testing of lower-level modules.

The principal phases of integration are: 1) system control, data handling, and man-machine interface; 2) link control and analysis; and 3) network planning, status logging, and standby operation, each of which constitutes a major "build." As the system is fully integrated, a formal qualification test will be conducted to verify that all of the system requirements are met.

Conclusions

The system control concepts addressed in this paper were developed for the network control requirements of the NATO III Satellite Communications System, which as a military system, has the potential in a conflict scenario of significantly greater variation in communications demand and environment than in a civilian or commercial network application. Changing signal attenuation and demanded traffic configurations dictate the need for effective network control to provide efficient response to network demands. The control subsystem discussed consists of two system control centers, an automatic data reporting system (ADRS) serving as the communication link among the SCCs and the satellite ground terminals, and a command, monitor, and display (CM&D) subsystem that monitors and commands components of the satellite ground terminal equipment to provide an efficient operation.

The control system software cycle includes top-level and detailed design, coding, integration, and testing phases. Top-level functional decomposition, modular structure, and an example of detailed design are discussed. Concepts for integration and testing are described. All of the above concepts, except for formal qualifications testing, have been implemented, with the next step being the formal qualification test.

In summary, this paper provides the present status of the control system design, development, integration, and testing for NATO SATCOM III.

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