ADVANCED TT&C FOR THE AIR FORCE SATELLITE CONTROL FACILITY CONCEPTUAL OVERVIEW

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ABSTRACT

The Department of Defense will be moving their essential space resources into the EHF spectrum which, together with new signal structures, will counter the impacts of jamming, nuclear effects, and electronic intelligence intercept. The Air Force Satellite Control Facility (AFSCF) project for incorporating the new Satellite Data Link Standards (SDLS) into its existing antenna and communication network is described. Also, the signal structure concepts, system architecture, EHF user programs, interoperability factors, and finally, implementation plans. Taken together, these factors will implement a new SDLS Military Standard for space links.

WHY MOVE TO EHF?

Satellite communication at EHF provides the bandwidth necessary to accommodate wide band users. EHF will also support effective spread spectrum and coding techniques for narrow band users, which will assure jam resistance and transmission through a nuclear-disturbed medium.

Future threats will consist of jamming attacks; nuclear effects such as EMP and scintillation from exoatmospheric nuclear bursts; and, electronic intelligence emitted by communication links being utilized by aircraft, spacecraft, and other platforms to localize, exploit and destroy radiating sources.

SURVIVABILITY/INTEROPERABILITY CONCEPT

Threats other than the above include sabotage, natural disasters, civil disorders, political instability, and diplomatic changes. Figure 1 illustrates that redundant nodes such as the Consolidated Operation Center (CSOC) and the Satellite Test Center (STC) negate the effect of many threats. Common Mobile Control System (CMCS) provides the ultimate in survivability. Frequent moves and concealed halts lower other contributions to the the probability of detection. Finally, host spacecraft relay packages to CONUS resources reduce the dependency on overseas ground stations.

S-BAND SCINTILLATION

Exoatmospheric nuclear explosions radically disturb the upper atmosphere and ionosphere for many hours. These disturbances cause serious phase and amplitude distortions of spacecraft data links as illustrated in Figure 2.

PROJECT DEFINITION

The Advanced TT&C (ATT&C) project is being utilized to implement Satellite Data Link Standards requirements. The primary objective is to provide survivable TT&C linkage with future spacecraft. The SDLS will be the link used by all future DOD spacecraft and ground support systems requiring wartime survivability. Physical implementation will EHF use up link/down link frequencies, as well as laser and RF cross links.

STANDARD ATT&C FUNCTIONS

Figure 3 illustrates a typical functional flow of data through an ATT&C uplink. Data is formated by multiplexing access control information with commands or communication data. Authentication words are added as needed. The data stream is encrypted to provide data privacy. Authentication prevents spoofing or unauthorized clear playback of recorded commands. The same unit, using a different crypto key controls the frequency hopping sequence for transmission security and crypto access control cover. Interleaving reduces problems with nuclear scintillation and pulse jammers. The data stream is multiplexed with other users as necessary, frequency hopped, and transmitted by a 250 watt transmitter. Planned antennas range between 2 and 33 feet. The larger sized antennas (up to 33 feet) are being considered for fixed installations.

GENERIC INTERNET LINKS

Figure 4 illustrates interoperable nodes and cross links. These are made possible using standardized networks and spacecraft.

SIGNAL STRUCTURE CONCEPTS

The SDLS uses frequency hopping, forward error correction, and interleaving to improve survivability against jamming and nuclear effects. The charts in this section conceptually illustrate techniques that improve SDLS robustness. The concept descriptions are intended to be informative rather than rigorous.

CHIP GENERATION OF SIGNAL FREQUENCY PERMUTATION AND FREQUENCY HOPPING

Figure 5 illustrates how frequency slots are assigned by cypher key to assure future hop path frequencies cannot be a priori determined by an enemy. These steps provide transmission security (TRANSEC) antijam resistance, and low probability of intercept. Low probability of intercept is achieved by using a narrow beam as well as the previously described unpredictable spectrum location. Other transmission security is achieved by real time computation of antijam functions such as spread spectrum, time, and frequency permutations.

Information is convolutionally coded for error correction, interleaved to avoid burst errors and uses redundant chip generation and combining for AJ robustness. The resulting signal structure is directed towards negating nuclear scintillation effects and pulse jamming. Further improvement is provided by repeating the information in several frequency slots.

FORWARD ERROR CORRECTION ENCODING CONCEPTS

Figure 6 illustrates with an analogy how convolutional coding and soft decisions are used to correct errors. The written language is highly redundant and uses a system similar to the binary convolutional coding scheme implemented in SDLS. The language uses many more symbols and words than are needed to represent the message and ideas. If we change a letter, we receive a mutilitated but recognizable message, rather than one with errors. Similarly, convolutional coding introduces redundant binary information. The redundant information contains sufficient information to support error correction.

VITERBI DECODER PERFORMANCE

The performance of various constraint lengths and possible bit error rate improvements is shown in Figure 7. It can be seen that a 3 dB improvement from coding is equal to reducing transmitted power requirements by 1/2. Such improvements are attractive for use in space links based on power limited spacecraft. The Viterbi convolutional decoder is easier to implement, and requires less hardware than a sequential block code, and is superior for links with good margins. Tripling redundancy instead of doubling produces a slight improvement, but the use of a soft decision in place of a hard decision is more significant A soft decision technique examines the probability of data flowing through each possible path of the trellis, and selects the most probable one. This produces a 2 dB improvement over evaluating the correctness of each pair of bits as they occur.

INTERLEAVING

Interleaving data prevents an error burst from propagating when used with the previously described convolutional coding error correction technique. Presume seven words of seven bits each. Interleaving systematically rearranges the entire group of bits so that the first interleaved word consists of the first bit from each raw word, the second interleaved word consists of the second bit from each raw word, and so on. Figure 8 illustrates this process and the result.

RAIN ATTENUATION

Outages from rain interference rapidly increase when using frequencies above 10 Ghz. Figure 9 portrays rainfall effects in the D_2 region[1]. For example, the east coast of the USA has such attributes. EHF rainfall induced outages are undesirable. However, the bandwidth provided defeats jamming and assure a low probability of intercept. Availability of these features in wartime is a satisfactory tradeoff benefit against the penalty of occasional severe weather attenuation.

THE AFSCF WITH ADVANCED TT&C CIRCA 1990

As indicated in Figure 10, Two key ATT&C items are being implemented within the overall AFSCF. They are: (1) crosslinks between host satellites, and (2) the retrofiting of an EHF capability into the Common Mobile Control Systems. Both elements are directed towards achieving a high AJ capability and a low probability of intercept. Together with these modifications, the entire AFSCF system is balanced towards achieving operational reliability by use of fixed (as well as mobile) sites to provide greater link margins. Fixed sites also can provide in depth satellite engineering support operations at low cost. Fixed site vulnerabilities are balanced by mobile resources, which support survivability. Finally, cross links for CONUS connectivity provide reduced overseas site dependency.

SPACECRAFT CROSS-LINK CHARACTERISTICS

The AFSCF plans to use the standard RF cross link for TT&C relay to CONUS ground terminals. A proposed system is illustrated in Figure 11. Descriptions are provided of antenna size, weight, power, and data rates for deployment aboard host relay satellites (and mission spacecraft).

THE AFSCF ISSUES AND STUDY TASKS

The AFSCF is studying the following design problems, which are directly related to satisfying ATT&C requirements. The first two are rapid low angle acquisition and precision ranging. Study subjects within the EHF frequency region are: an omni antenna system, an increased precision ranging system with increased distance and rate capabilities over those available today, and a system proof of concept evaluation. This last study will use aircraft flybys to validate unique performance characteristics of ATT&C systems. Another design problem is posed by the requirement for an unstabilized spacecraft omni antenna. Such spacecraft cannot point a transmitting antenna at a receiving antenna or orient a receiving antenna to receive commands from a distant transmitter. Omni antennas can provide an economical method of communicating with an earth terminal when compared to use of precision pointed directive arrays, even though two significant difficulties are present. These are: (1) extremely high attenuation of over 40 dB in certain instances caused by weather seen at low elevation angles, and (2) the reduced capture area of the omni antenna, which drastically reduces EHF link margins when compared to those available in the S-band region.

Within constraints established by such problems, the basic system implementation approach is to avoid expensive R & D by use of cost effective adaptations of existing designs.

Note 1: R. Kaul, R. Wallace and G. Kinal (1980), “A propagation Effect Handbook for Satellite System Design”, p. 3 - 22.

CONCLUSION

Standardized EHF ATT&C links are necessary to support high priority space resources that require a robustness in a jamming and nuclear environment. Narrow beams and frequency hopping provide for a low probability of intercept. Joint operation of coding and internetting are essential for negating nuclear scintillation effects. The standardized signal structure and cross links for a CONUS relay increase connectivity flexibility and provide interoperability. Real time data relay and increased contact time improve operational effictivity. The AFSCF is the largest U.S. ground TT&C network. It is global in deployment. As it increases its quantity of survivable mobile resources and implements EHF ATT&C, the AFSCF will play a key role in support of National and DoD space programs.

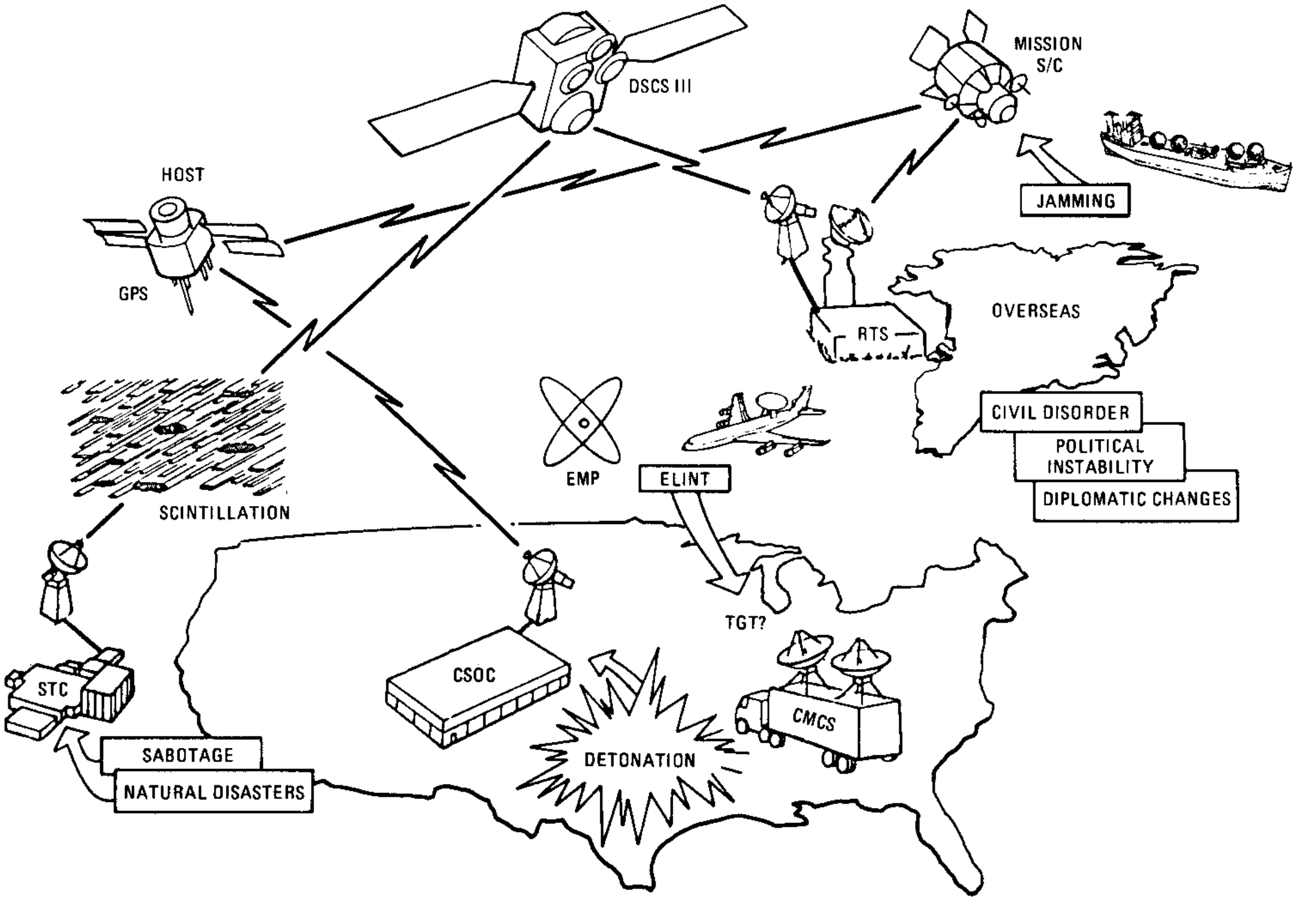


FIGURE 1 SURVIVABILITY/INTEROPERABILITY CONCEPTS. The threats to space resources and their ground support elements are illustrated. The alleviation of the threats by cross links to CONUS, improved signal structure, mobile resources, and elimination of single nodes are indicated.

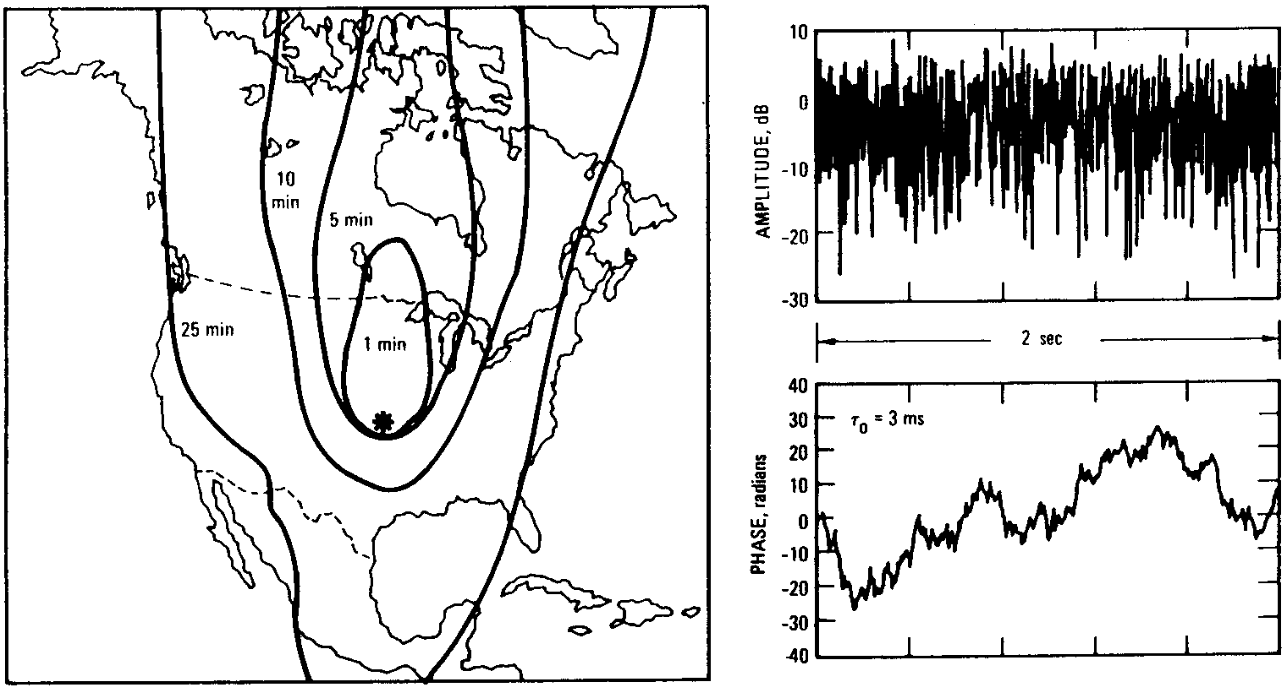


FIGURE 2 SCINTILLATION-S BAND. Exoatmospheric nuclear explosions radically disturb the upper atmosphere and ionosphere for many hours causing serious phase and amplitude distortions of spacecraft data links.

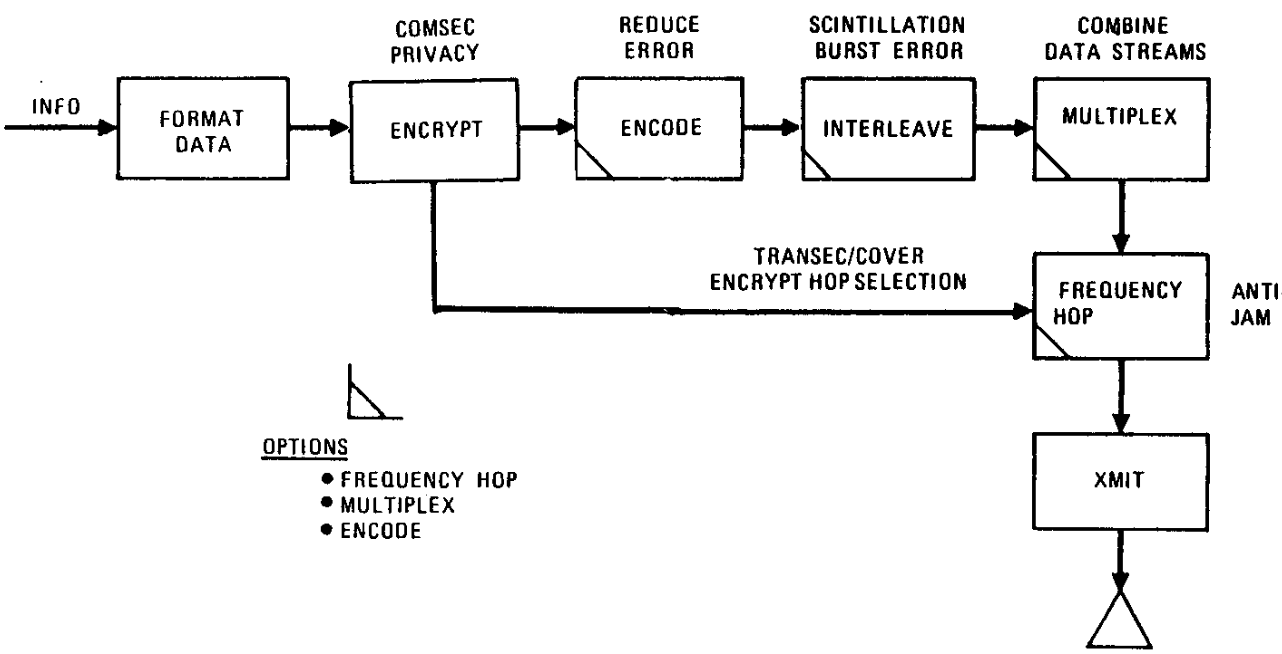


FIGURE 3 STANDARD AND ATT&C FUNCTIONS. A typical functional flow of data through an ATT&C station uplink.

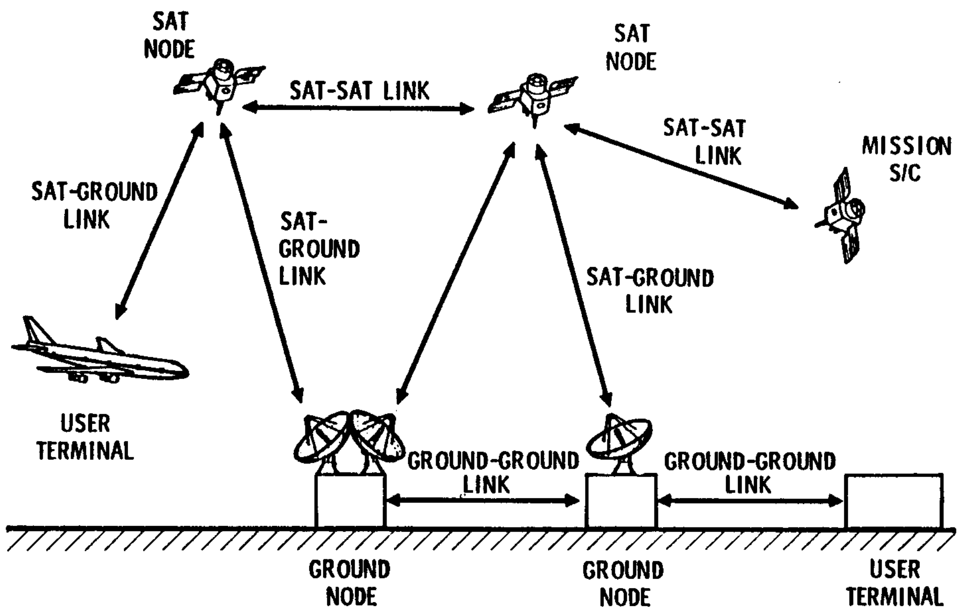


FIGURE 4 GENERIC INTERNET LINKS. Interoperable nodes and cross links are made possible using standardized networks and spacecraft.

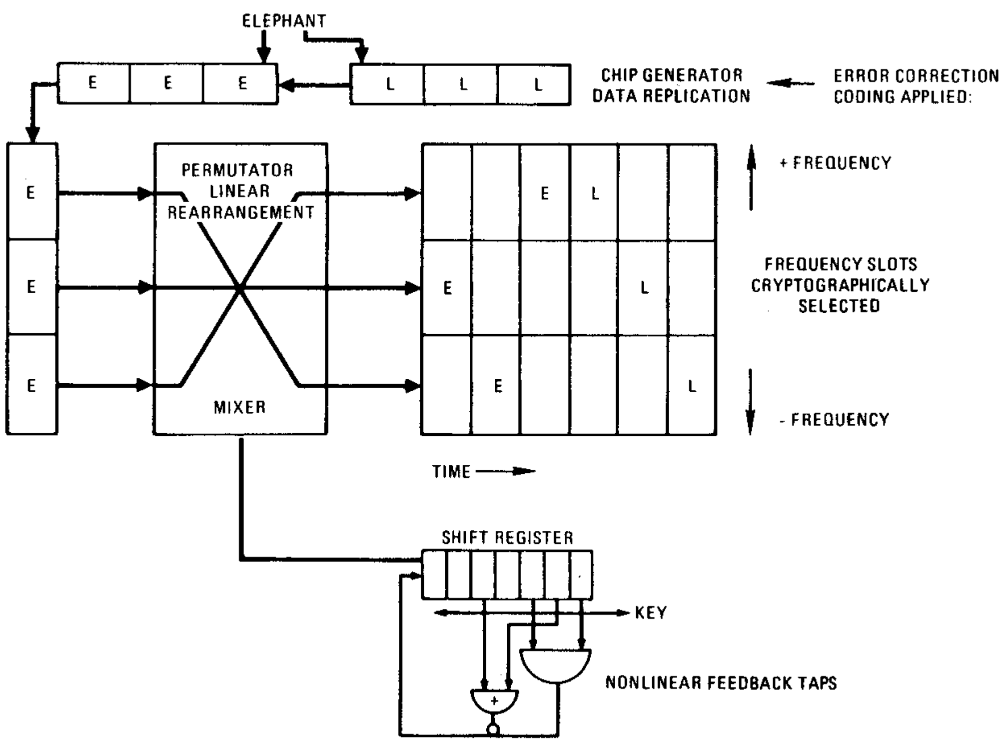


FIGURE 5 CHIP GENERATION, PERMUTATION AND FREQUENCY HOPPING. Frequency slots, assigned by a cypher key are used to assure future hops cannot be determined by an enemy thus providing transmission security (TRANSEC) antijam resistance, and low probability of intercept.

- 0 INFORMATION: 1 6 2
- 0 RATE 1/3 ENCODE O N E S I X T W O
  - THREE LETTERS REPLACE ONE NUMERIC: R = 1/3
  - SDLS WILL USE RATE 1/2 ENCODE: 2:1 OR R = 1/2
- 0 CONSTRAINT LENGTH: K=4 FOR HISTORIC DATES, USA
  - -1492- -1776- -1812- -1914- -1941-
  - SYNERGISTIC IMPROVEMENT OF ERRORS POSSIBLE ? = ERROR
  - 17 ? 6 = 1776
  - SDLS USES CONSTRAINT LENGTH SEVEN
- 0 COMBINE ENCODING
  - ONE SEVEN SEVEN SIX
- 0 ERRORS
  - ONE SEVEN ?EV?N SIX

FIGURE 6 FORWARD ERROR CORRECTION ENCODING CONCEPT. An analogy on how convolutional coding and soft decisions are used to correct errors.

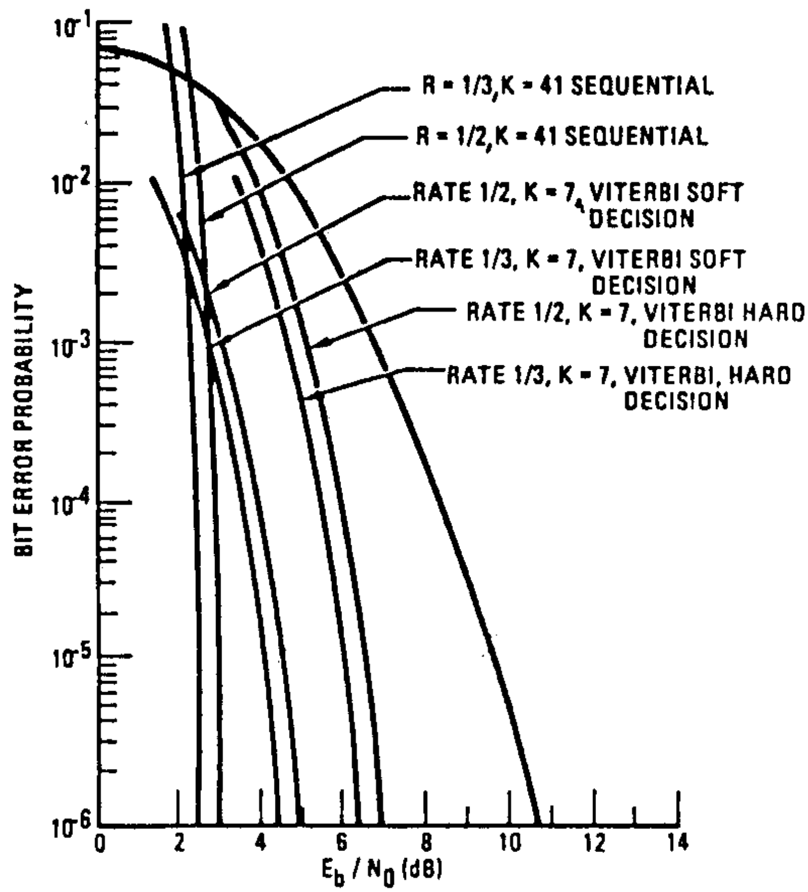


FIGURE 7 VITERBI DECODER PERFORMANCE RATE 1/2 vs RATE 1/3. A chart indicating the performance of various constraint lengths and possible rates of bit error Improvements.

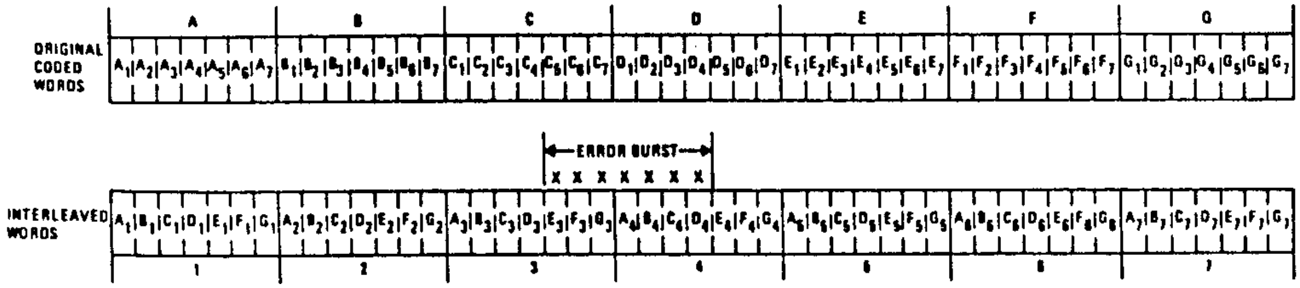


FIGURE 8 INTERLEAVING. Interleaving data prevents the error burst from propagating when used with the previously described convolutional coding error correction technique.

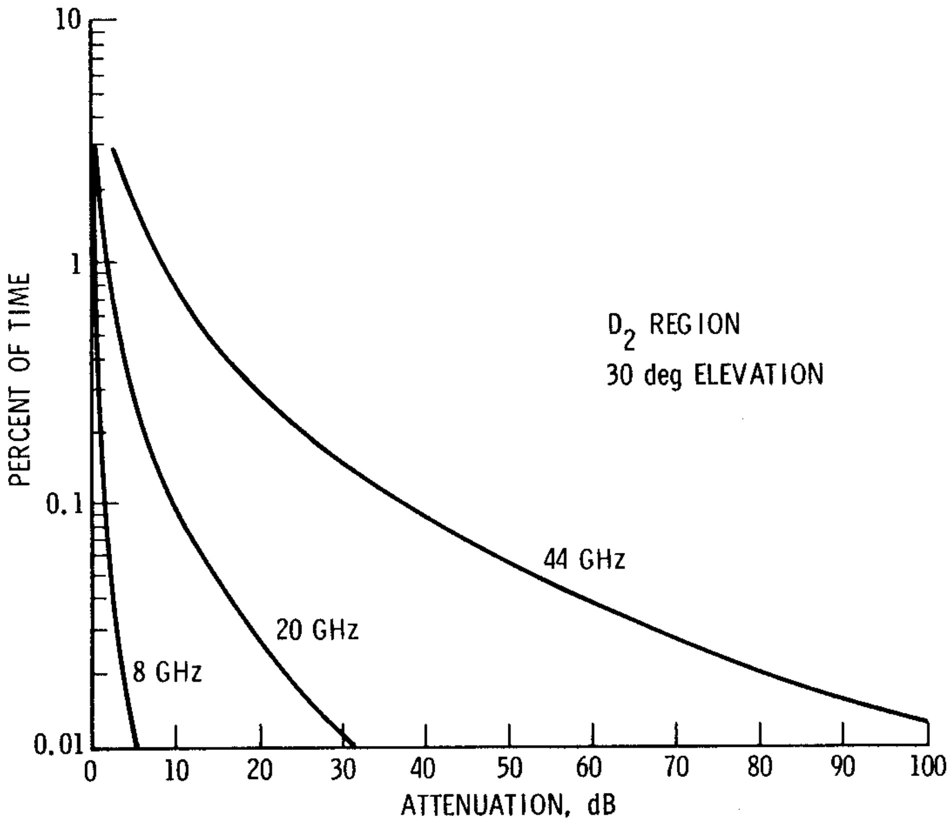


FIGURE 9 RAIN ATTENUATION. The outage from rain interference rapidly increases with frequencies above 10 GHz.

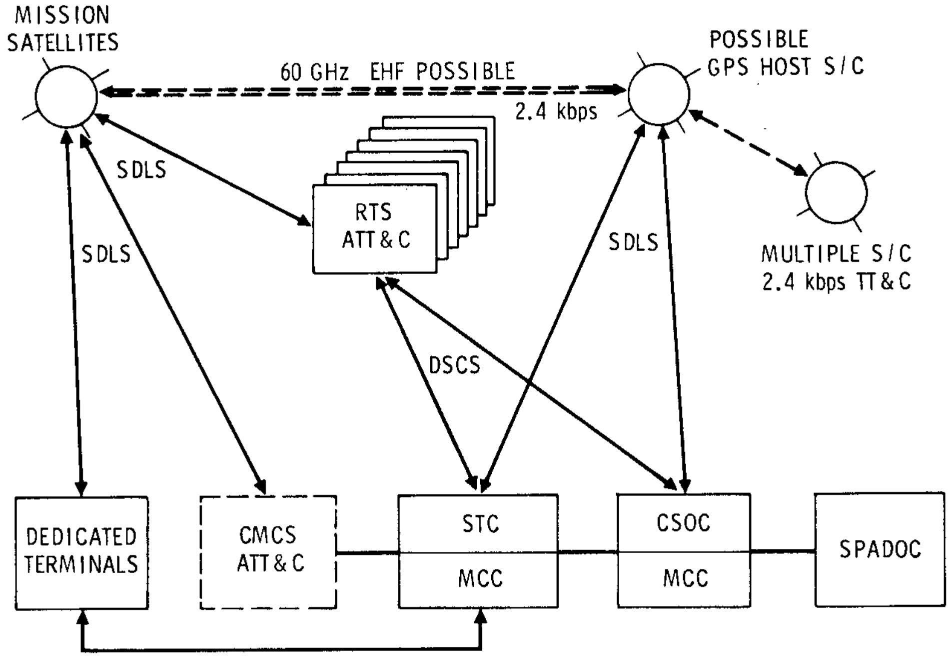
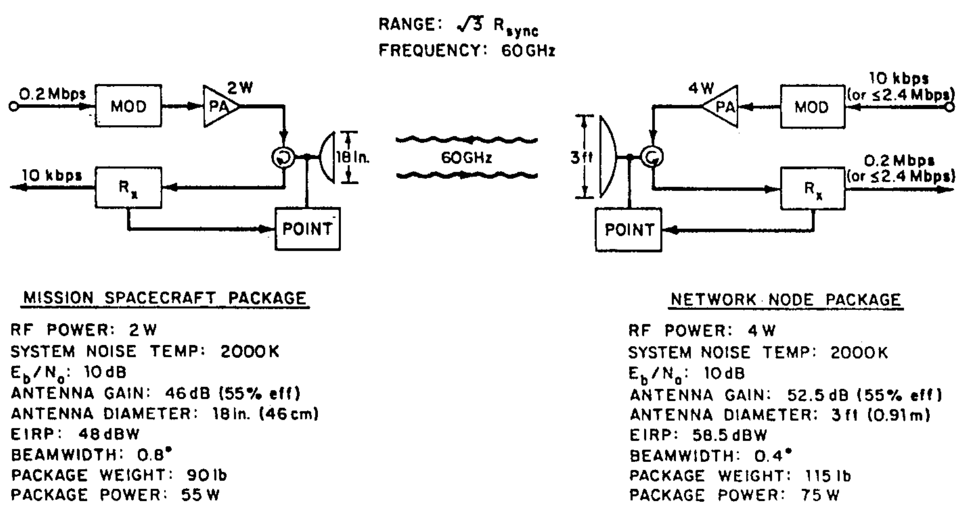


FIGURE 10 AFSCN WITH ADVANCED TT&C CIRCA 1990. The key items being implemented are the crosslinks to a host satellite and the retrofiting of an ATT&C EHF system into the common mobile control systems for high AJ capability and low probability of intercept.



Technology assumptions for 60 GHz TTC access link (200 kbps). As a cross-orbit trunk, the network node package can handle 12 TTC channels (2.4 Mbps) bi-directionally.

Source Lincoln Labs

FIGURE 11 SPACECRAFT CROSS-LINK SYSTEM PARAMETERS. Antenna size, weights, power, and data rates for deployment aboard host relay satellites and mission spacecraft are estimated for a proposed cross link system.