THE INTRODUCTION OF PACKET SATELLITE COMMUNICATIONS

Robert E. Kahn

Advanced Research Projects Agency

Abstract

The preparations which led to the SATNET Experiment are discussed in this paper. Various packet satellite tariff considerations and architectural issues are presented along with a summary of future plans for use of the technology.

1. Introduction

This paper reviews the process which led to the introduction of packet satellite technology in the 1970s. The development of this technology was undertaken by the Advanced Research Projects Agency (ARPA) in order to evaluate its utility for efficient long haul computer communications with a potentially large number of geographically distributed users. This effort was undertaken in conjunction with participating organizations in the U.K. and Norway, but does not necessarily reflect their views on this subject.

The most notable example of this technology is the Atlantic Packet Satellite Network, known as SATNET, which has been in operation on the Atlantic Intelsat IV satellite since late 1975 and which currently serves a community of researchers in the U.S, the U.K. and Norway. Underlying the SATNET technology is the basic packet switching technology which was first introduced during the late 1960's. The November 1978 IEEE Proceedings contains a comprehensive treatment of packet communications technology and includes a paper on General Purpose Packet Satellita Networks which provides a good introduction to the subject [1,2].

SATNET consists of a single broadcast channel shared by multiple earth stations which use Time Division Multiple Access (TDMA) and emit packets according to a channel access protocol. These earth stations may be connected to one or more subscriber networks. Each earth station contains a programmable satellite processor (a controller and related electronics) which implements the satellite channel protocols and interfaces. The system provides complete connectivity between all the participating earth stations and allows dynamic allocation of the satellite channel among them. Different priority levels may be supported efficiently on the same channel without unnecessary preallocation or preemption of resources. The broadcast property of the channel enables a transmission from one earth station to be received by all the others including itself. Both conferencing and delivery of multiple address packets can be achieved efficiently as a result.

The Arpanet was the first example of a packet switched network which used point-to-point terrestrial lines (across the U.S.) in a store and forward system [3,4]. Following the installation of the first Arpanet nodes, a number of papers appeared in the literature on the application of packet switching to multiple access radio channels [5,6,7,8]. The ARPA-sponsored effort at the University of Hawaii was the first to demonstrate burst transmission of packets by radio for computer access by terminals within line of sight of the computer center. In this system, called the ALOHA system [9,10], packets were simply transmitted when they were ready to send - at random instants of time. No explicit control of the radio channel was invoked. Rather, on occasion, packets would collide in the air, destroying each other and would be retransmitted at a later random time. The multiple access nature of this system resembled a packet satellite net, except that the terminals were much closer to and quite unequally spaced from the computer center which (like a satellite) formed the hub of the system. The Hawaii researchers extended the concept of radio packets to satellite communication directly, and experimentally verified the concept using test packets over NASA's ATS-1 satellite between Hawaii and NASA-Ames. The technique of operating a Packet Satellite Net in an uncontrolled fashion became known as "Pure Aloha".

A significant body of theoretical work on the analysis of Aloha Systems appeared in the literature in the early 1970's and various improvements on the original random transmission technique were proposed and evaluated [11,12]. In the Slotted Aloha technique, first introduced by Roberts, the time axis at the satellite is divided into equally spaced intervals called time slots which hold a single packet [13]. Under the Slotted Aloha regime, packets can only be transmitted starting at the beginning of a slot. For fixed length packets and Poisson traffic arrivals, the capacity of the slotted system is twice that of the unslotted system due to the reduced number of collisions at light traffic loads. In both the slotted and the unslotted case, some form of stability control is needed [14,15]. For efficient use of a packet satellite channel, where the one-way transit time is much larger than the time to send a packet, some form of satellite channel allocation strategy is appropriate [16]. A priority oriented demand assignment technique was developed for dynamic allocation of capacity and is currently in daily use in SATNET [17].

Both simulation and analysis were used extensively and effectively in investigating these and other channel access schemes. However, this work was unable to deal effectively on a purely theoretical basis with any of the practical problems associated with development of the technology. Access to an experimental system was essential to address topics such as fault detection and isolation, system status monitoring and debugging, interfacing to terrestrial networks and gateways, software structure and performance. It was feasible to carry out a test of the technology on one of several existing satellites and it appeared as if existing ground stations could be used in a packet mode of operation with only minor modifications to provide external on/off control of the carrier by a programmable satellite processor at each earth station. The packet satellite technology was also seen as a potentially useful long term adjunct to existing network technology for long haul applications involving conferencing, multi-destination broadcasting and especially to provide connectivity between a large number of sites (each with low duty cycle traffic) using a small fraction of the leased channel bandwidth that a fully connected network of point-to-point circuits would have required.

In the 1973-1974 time frame, the only viable choices for such a test (from the U.S. point of view) were the Intelsat satellites, the NASA experimental satellites and one of the several military satellites. The Intelsat system was a preferred choice for this activity because it could be made available most easily and had the potential for supporting the resulting technology on a commercial basis upon completion, if it proved to be economic. The military satellites were less appropriate choices as there was not yet a stated requirement for packet satellite service in the military. At the same time, international interest in packet switching was growing significantly, and possible requirements for interconnection of domestic packet networks in the different countries were identified. In 1973, the ARPANET had just been extended to Norway and the U.K., and experimental use of the ARPANET was proving to be quite worthwhile for research purposes.

This is the context in which the subject of an experimental program on packet satellite technology was first raised with the British Post office, with the Communications Satellite Corporation (Comsat), and subsequently with the Norwegian Telecommunication Administration (NTA) and Norwegian Defense Research Establishment (NDRE). In the following section, the preparations for the SATNET experiment are outlined along with the approval process which was required.

2. Preparing for the SATNET Experiment

In 1974, the U.K. Post Office agreed to support the SATNET experiment by contributing the U.K. half of the satellite link and by providing access to the necessary earth station equipment in England. A programmable satellite processor was installed at the Goonhilly earth station and connected back to a gateway at the ARPANET node on the premises of University College London (UCL) with a 48 Kbps communication line. UCL was prepared to accept the main research responsibility for the U.K. participation in the SATNET program, and subsequently did so.

Also in 1974, Comsat agreed to U.S. participation in such an experimental activity, but only if it were carried out under the auspices of one of the several U.S. International Record Carriers (IRCs) which historically have played the role of intermediary in bringing international data services to the end customer. Comsat is the U.S. representative to Intelsat. When the SATNET project was being formulated, Comsat also operated both the space segment under contract to Intelsat and the U.S. earth stations for the consortium of U.S. owners. Intelsat itself now operates the space segment.

The only generic classes of service which could be offered by Comsat were those specifically approved (tariffed) by Intelsat. Clearly, a packet satellite service was not among them. After a period of discussion within Intelsat lasting several months, an Intelsat tariff for a multi-station service was approved in late 1974. The SATNET program was initiated in September 1975 with one Intelsat standard A (30 meters) earth station at Etam, West Virginia and a similar one at Goonhilly Downs, England. Within Norway, the interactions with the NTA were handled entirely by the Norwegian Defense Research Establishment. While Norwegian participation in the SATNET program had started with the first meeting of the researchers in 1975, their active participation on the channel began in late 1977 using the Nordic earth station at Tanum, Sweden. Shortly thereafter, Comsat Laboratories made preparations to participate actively with a small Unattended Earth Terminal (UET) at Clarksburg, Maryland for system diagnosis and evaluation. The UET differed from the three standard A earth stations in that it had only a 10 meter antenna and could only receive at 16 Kilobits/second while the other stations could receive at 64 Kilobits/second. All four stations can transmit at 64 Kilobits/second, but the large stations must reduce their transmission rate to 16 Kilobits/second to talk to the UET.

The technical aspects of the SATNET experiment are not addressed in this paper. Other companion papers address both system level and experimental aspects of the program [18,19,20,21]. In the remainder of this paper, the relevant tariff considerations will be discussed and two key architectural issues will also be considered.

3. Intelsat Tariffs

The new Intelsat tariff which was approved in late 1974 was for a new kind of service known as Multi-Destination Half-Duplex (MDHD). Simply stated, MDHD allows one or more members of Intelsat to jointly share a common channel on any of the Intelsat Satellites for a modest MDHD payment to Intelsat. The normal leased service offerings from Intelsat to its members are a point-to-point service between two earth stations and a broadcast service from one prespecified (but fixed) earth station to at least two others. The point-to-point service can be either half-duplex (one way) or full-duplex (two-way). The broadcast service utilizes only one channel, as a reverse path is not included.

The MDHD capability may be viewed as an extension of the broadcast service to allow more than one prespecified earth station to transmit. MDHD allows all participating earth stations to transmit using their own channel access protocol to resolve contentions.

To any member country already participating in an MDHD service, the added cost is nominally zero to allow additional earth stations to share the MDHD channel. This assumes that capacity limitations are not exceeded and that coordination among a larger number of sites costs the same. However, a payment must be made to Intelsat by each member country which chooses to join (share) an existing MDHD channel, so the total payment received by Intelsat for MDHD service grows linearly with the number of countries. The reasons for a choice of tariff in which the cost per country is independent of the number of participants depends, in part, upon the political structure of Intelsat. The subject of PTT tariffs to the end customer, although not specifically discussed in this paper, would generally include earth station and terrestrial charges, as well as space segment charges.

If we assume Intelsat normally charges a member C per one-way channel of a certain capacity for a total of 2C counting both ends, then the same revenue would be gathered if each of the participating members in an MDHD channel were charged 2C/N apiece (assuming N participants). The members, in turn, could base charges to their customers on these costs plus the added costs of ground station equipment and terrestrial interconnection. This kind of formula in which the space segment charge is independent of the number of earth stations appears well-suited to domestic services where all the earth stations are owned by one authority. However, this formula poses several problems when applied to the international situation, where the earth stations are separately owned and operated.

First, the rate base for each participating country would fluctuate as a function of the number of participating countries, making financial management and planning awkward and unpredictable at best. Second, and more important, the voting rights of each member country in Intelsat are a function of its total payments to Intelsat. Primarily, for that reason, the Intelsat MDHD tariff was fixed to be a constant C per channel per country.

The Intelsat broadcast tariff illustrated in Fig. 1(a) shows one transmitter which is charged C and four receivers each of which is charged C/2 for a total of 3C. Since at least two receivers must be present for a broadcast service, the minimum charge is 2C (which is identical to the half duplex point-to-point tariff between two sites). The revenue produced by the broadcast tariff increases linearly with the addition of more ground stations at an increment of C/2 per added receiving station.

The MDHD tariff illustrated in Fig. 1(b) shows each participating country being charged C for the right to receive and transmit on the same channel. The net payment to Intelsat, 5C, is almost double the charge for the simple broadcast case. However, the value received for this added cost is full N-way connectivity since any of the earth stations can transmit to the others at any time according to the chosen channel access protocols. The MDHD tariff is also considerably cheaper than that for N distinct broadcast channels to implement N-way connectivity (NC vs. $[NC + N(N-1)C/2]$). Along with the initial higher cost of N broadcast channels would come N times the capacity, however, regardless of whether it can be used effectively or not.

With these existing tariffs, the cost per country normalized by total number of channels of network capacity available to the N earth stations is C for the MDHD case and $[C + (N-1)C/2]/N = (N+1)C/2$ for the case of N broadcast channels. If existing MDHD tariffs are extended to channels with a higher bandwidth using a "linear extrapolation" of the current tariff, the charges for obtaining the added capacity with multiple lower capacity broadcast channels will be half as much as the single MDHD channel as the number of participating earth stations becomes large. Since this ratio reflects only the current tariff structure, the ratio could be changed (e.g., become closer to unity) with a non-linear tariff revision applicable to higher bandwidth channels.

From an architectural point of view, the use of multiple broadcast channels has both positive and negative features which are identified in section 6. However, in most applications, it is doubtful whether initial network-wide traffic will be large enough to justify commencing service with more than a single MDHD channel.

4. COMSAT and IRC Filings in the U.S.

The U.S., U.K. and Norway participation in SATNET has been on an experimental basis and a service has not yet been offered to customers in any of these countries. In the U.S., Comsat filed a tariff with the FCC in 1975 to offer an experimental packet satellite capability to ARPA and its designated contractors via one of the IRCs. The service Comsat offered was based on the MDHD service obtained from Intelsat, and was augmented as required with the programmable satellite processor at the earth station. In its filing, Comsat also referred to its augmented service as MDHD.

Comsat bought or leased all the necessary ground station equipment to provide the experimental service as for a normal commercial service offering. In a competitive selection, Western Union International (WUI) was chosen by the U.S. government from among the IRCs to provide the MDHD service to the ARPA program. WUI, in turn, filed a tariff with the FCC to offer MDHD service as obtained from Comsat, which they augmented with a terrestrial circuit before supplying it to the government.

The statement of work which accompanied the government's request for proposals was unusual in that it did not cite any specific destination or customer location abroad. Rather, it simply asked for an MDHD channel from the U.S. to an unspecified point in the U.K. and stated that all of the U.K. costs were to be assumed by the British Post Office. A point of contact in the Post Office was identified. The request also stated that additional unspecified destinations might have to be connected subsequently, as Norway eventually was.

To validate the initial delivery of the service and to verify restoral of service in the event of outage, only a loopback test from the U.S. customer site (which was specified to be the Seismic Data Analysis Center in Alexandria, Virginia) to the satellite and back was required. The payment to WUI was not dependent on the participation (or performance) of any other country (or its equipment). However, the WUI and COMSAT tariffs both included a small charge proportional to the number of participating sites for coordination.

A diagram of the MDHD payment flow during the experiment is shown in Fig. 2.

5. SATNET Experiment

The SATNET Experiment was conducted nominally during the period from September 1975 through September 1978 and involved researchers from each of the three participating countries. The basic physical architecture of SATNET was dictated by many programmatic considerations (e.g. use of existing ground stations and satellites) so the actual hardware configuration merely reflects what was available for use in the experiment. However, the logical architecture of the system has been a subject for research and has constantly evolved during the course of the program. Neither the software architecture nor the system protocols were prescribed in advance and the non-hardware parts of the system interfaces were also allowed to evolve, which they did. Each was a major subject for investigation and exploratory development during the course of the project. The resulting logical architecture will be very useful in designing a more advanced follow-on system. In addition, an effort was undertaken to develop and demonstrate a high performance digital burst modem and error control unit for possible operational use with SATNET after the experiment.

A major decision in the program was to separate the SATNET development and testing from the closely related internetting research activities which were just getting underway. It was decided to pursue the internetting research using a separate minicomputer gateway in each country simultaneously connected as a Host on SATNET and as a Host on the Arpanet [22,23]. This arrangement left enough flexibility to pursue gateway related research without requiring software changes (in real-time) to SATNET or Arpanet. The gateway software could have been incorporated within the physical confines of either SATNET or Arpanet, or split between them. However, keeping it separate for the purposes of the experimental program provided maximum flexibility to the internetting researchers, many of whom were also working on SATNET, Arpanet or other ongoing network related programs without unnecessarily distracting those SATNET researchers who did not need to be deeply involved in the internetting work at that time.

Technical direction of the program beginning in September 1975 was the responsibility of Linkabit Corporation, San Diego, California who prepared a comprehensive test plan to guide the conduct of the experimental program. Major participants were Comsat, Bolt Beranek and Newman, University of California at Los Angeles (UCLA) and the Defense Communications Agency in the U.S., University College London and the Post Office in the U.K., and NDRE and NTA in Norway.

Coordinating a program involving participants from multiple countries was an important challenge that was met at several different levels. Quarterly review meetings were held (rotated among the different locations) and attended by all the participants. Technical progress was reviewed at these meetings, technical issues were discussed and resolved and plans for each succeeding quarter were refined. Research issues and results were documented and circulated in a series of informal working group notes. The ARPANET played a particularly important role in executing the effort as well as in coordinating it. It provided the means by which the satellite processors were down-line loaded and debugged, and the means by which SATNET itself was controlled and monitored as it was being developed. The message passing capability of the hosts on the ARPANET were used to keep all participants informed of technical progress, system status, often by direct reporting from the programmable satellite processors in SATNET, and to resolve questions and coordinate experiments on a day-by-day basis. Without such a capability, it is doubtful that the overall experimental program could have been carried out successfully.

The main results of the experiment are being documented by Linkabit Corporation (with inputs from all the participants) in a final report to be available shortly. A summary of the findings show that the SATNET experiment demonstrated the feasibility of the packet satellite technology, illuminated many of the most important technical and non-technical issues and provided a system that can support advanced computer communication research applications. Although the subject of packet voice has not been emphasized in this article, it played an integral role in the SATNET design. SATNET is the only operating long haul packet switched network in the world that has been designed to handle both packet switched voice and data.

6. Architectural Issues

Two architectural issues arose during the course of this project which are appropriate to single out for mention. The first issue is selecting the functionality that ought to reside in the processor which is colocated with the rest of the earth station equipment and the functionality that ought to reside at the terrestrial interface (to the earth station) which might be located some distance from it. The second major issue concerns the means of increasing the overall traffic handling capacity of the system. Each of these issues are briefly mentioned below.

a. Functionality of the Earth Station and its Terrestrial Interface

Although not all the functions implemented in SATNET need to reside at the earth station, a minimum set of functions must be located there to control timing and access to (and transmission on) the satellite channel. Parts of the functionality might be moved to a terrestrial location distant from, but connected to, the earth station by a communication line. One attempt at the definition of the functionality is given in [24]. In particular, certain aspects of the functionality which deal with multiplexing traffic from many users into a composite stream to the earth station could probably be relocated without penalty in performance provided delay or unreliability is not added outside the earth station. Accounting and other administrative functions could also be remoted from the earth station without penalty.

b. Expansion of Network Capacity

Although a single 64 Kilobits/second channel is utilized in the SATNET experiment, this capacity clearly would be insufficient for many applications. The capacity of a SATNET system could be expanded in several ways. First, it could be simply scaled up in data rate. The ability of a packet switch to handle multi-megabit/second data has been demonstrated [25]. This would suffice for an expansion of one or two orders of magnitude. A transponder can typically handle upwards of 60 Megabits/second, however, and the newer satellite systems are expected to support higher data rates still. Multi-processor systems seem capable of supporting these higher data rates on a single shared satellite channel without either increased delay in buffering or processing. However, the number of processors must grow linearly with capacity and special attention must be paid to communication between processors and with external devices.

A second alternative, which becomes attractive when the overall network traffic is high enough, is to incorporate dedicated uplinks using Frequency Division Multiple Access (FDMA). In this scheme, which is illustrated in Fig. 3, a separate processor at each earth station would be dedicated to handling traffic on each broadcast downlink and would pass along to a concentrator only those packets destined for its earth station. The capacity of the concentrator would then be sized to the throughput intended for that site which presumably would be much less than the total network traffic. In this scheme, a modification would be required at each existing ground station for each new addition to the net, which is a major disadvantage. However, it is highly modular and should be easy to upgrade in an operational system.

The use of multiple FDMA broadcast channels, one per site, reduces the earth station processing requirements but it also does not provide the flexibility that comes from the dynamic assignment of capacity in a TDMA system. A third alternative is a hybrid of cases one and two above in which some of the uplinks may be MDHD channels (using TDMA) while the rest may be broadcast channels each from a single source.

7. Future Plans

SATNET currently serves as the backbone for a number of innovative research applications and has become the primary packet transportation vehicle between the U.S. and Europe for computer communications and command and control research. Since May 1979, ARPANET access from the U.K. has run almost exclusively via SATNET on a provisional basis. It is planned to continue the use of SATNET as the primary link between ARPA and its research partners in Europe. The ARPANET link to London (via Norway) is scheduled to be taken down during the last quarter of 1979 after which the only available ARPANET access from the U.K. will be via SATNET. NDRE will utilize SATNET for research purposes; the only planned use of the remaining point-to-point ARPANET link from the U.S. to Norway will be for retrieval of seismic data, which was the original function of that line prior to its incorporation in the ARPANET in 1973.

Within the U.S., ARPA plans to use the SATNET technology as the basis for a domestic packet satellite channel operating at 3 Mbps with 5 meter antennas initially at Lincoln Laboratory, in Lexington, Massachusetts and USC/ISI in Marina Del Rey, California. Additional sites in the San Fransisco area and Washington, D.C. area will also be added. A major purpose for the domestic channel is to explore the use of the SATNET technology to support multi-user integrated packet voice and data communication. Only with the increased bandwidth will a test of this concept be possible using multiple speech and data sources including a mix of 2.4 Kilobits/second to 64 Kilobits/second speech transmission with graphics, facsimile and normal computer to computer traffic. The Defense Communications Agency also plans to utilize this technology along with ARPA for advanced research and development on DoD integrated data/voice networks of the future.

On the international scene, packet satellite technology may be useful for a wide variety of potential applications. One such possibility which is being offered as a service by the PTTs and the US Postal Service is Intelpost. This is an innovative new facsimile service which is being tested among several countries. If the current plans evolve, individual point-to-point links might be required between each participating country. A packet satellite system could support the initial Intelpost traffic with only one shared channel, with considerably less total satellite bandwidth than multiple point-to-point links would require and without noticeable degradation of performance.

Acknowledgments

This effort would not have been possible without the cooperation and support of the British Post Office and the Norwegian Telecommunications Administration; both organizations played a very central role in the program. Bolt Beranek & Newman (BBN), COMSAT, and Linkabit Corporation played significant roles in developing the packet satellite technology. COMSAT spearheaded the approval process. UCL, NDRE, UCLA, and COMSAT, with the assistance of BBN, carried out the measurement, testing and applications developments despite the large geographic distances from SATNET and each other which might otherwise have been a deterrent. The success of the program was due in no small measure to the technical direction provided by Linkabit Corporation.

References

[1] Special Issue on Packet Communications, IEEE Proceedings, Nov. 1978

[2] I.M. Jacobs et al, "General Purpose Packet Satellite Networks," IEEE Proc., pp. 1448 - 1467, Nov. 1978

[3] L.G. Roberts and B. G. Wessler, "Computer Network Development to Achieve Resource Sharing," AFIPS Conf. Proc., SJCC, pp. 543-549, 1970

[4] R.E. Kahn, "Resource Sharing Computer Communication Networks," IEEE Proc., pp. 1397 - 1407, Nov. 1972

[5] N. Abramson, "The Aloha System - Another Alternative for Computer Communications," AFIPS Conf. Proc., FJCC, pp. 695 - 702, 1970

[6] L.G. Roberts, "Extensions of Packet Communication Technology to a Hand Held Personal Terminal," AFIPS Conf. Proc., SJCC, pp. 295 - 298, 1972

[7] R. E. Kahn, "The Organization of Computer Resources into a Packet Radio Network," IEEE trans. on Comm., Vol. COM-25, pp. 169 - 178, Jan. 1977 (also in AFIPS Conf. Proc., NCC, pp. 177-186, 1975)

[8] L. Kleinrock and F. Tobagi, "Random Access Techniques for Data Transmission over Packet Switched Radio Channels, AFIPS Conf. Proc., NCC, pp. 187-201, 1975

[9] R. Binder et al, Aloha Packet Broadcasting - A Retrospect," AFIPS Conf. Proc., NCC, pp. 203-215, 1975

[10] N. Abramson and F. Kuo, Editors, Computer Communication Networks, Prentice Hall, Englewood Cliffs, N.J., 1973 (see chap. on the Aloha System)

[11] N. Abramson, "Packet Switching with Satellites," AFIPS Conf. Proc., NCC, pp. 695-702, 1973

[12] L. Kleinrock and S. S. Lam, "Packet Switching in a Slotted Satellite Channel," AFIPS Conf. Proc., NCC, pp. 703-710, 1973

[13] L. G. Roberts, "Aloha Packet System with and without Slots and Capture," ACM SIGCOMM, Computer Communication Review, Vol 5, No. 2, April 1975

[14] L. Kleinrock and S. S. Lam, "Packet Switching in a Multiaccess Broadcast Channel: Performance Evaluation," IEEE Trans. on Comm, Vol. COM-23, pp. 410-423, 1975

[15] S. S. Lam and L. Kleinrock, "Packet Switching in a Multiaccess Broadcast Channel: Dynamic

Control Procedures," IEEE. Trans. on Comm., Vol. COM-23, Sept, 1975

[16] L. G. Roberts, "Dynamic Allocation of Satellite Capacity through Packet Reservation," AFIPS Conf. Proc., NCC, pp. 711-716, 1973

[17] I.M. Jacobs et al, "C-PODA - A Demand Assignment Protocol for SATNET," Fifth Data Communications Symposium, Snowbird, Utah, 1977

[18] I.M. Jacobs et al, "Packet Satellite Network Design Issues," Proc. NTC, Nov. 1979, in this Proceedings

[19] P. T. Kirstein et al, "SATNET Applications Activities," Proc. NTC, Nov. 1979, in this Proceedings

[20] D. A. McNeill et al, "SATNET Monitoring and Control," Proc. NTC, Nov. 1979, in this Proceedings

[21] W.W. Chu et al, "Experimental Results on the Packet Satellite Network," Proc. NTC, Nov. 1979, in this Proceedings

[22] V. G. Cerf and R. E. Kahn, "A Protocol for Packet Network Intercommunication," IEEE Trans. on Comm., Vol. COM-22, pp. 637-648, May 1974

[23] V.G. Cerf and P.T. Kirstein, "Issues in Packet Network Interconnection," IEEE Proc., Vol 66, No. 11, pp. 1386-1408, Nov. 1978

[24] E.V. Hoversten and H. L. Van Trees, "International Broadcast Packet Satellite Services," ICCC-78 Conf. Proc., Kyoto, Japan, Sept. 1978

[25] S.M. Ornstein et al, "Pluribus, A Reliable Multiprocessor," AFIPS Conf. Proc., NCC, pp. 551-560, 1975

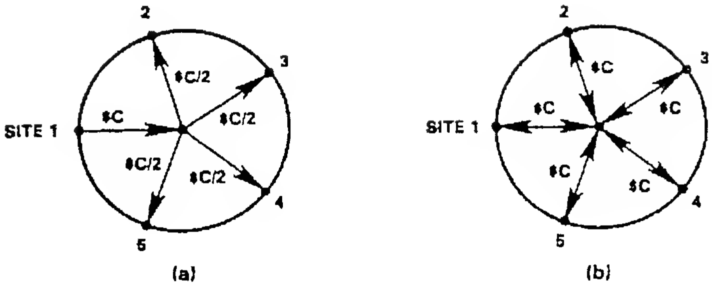

Fig. 1. (a) Broadcast Tariff. (b) MDHD Tariff

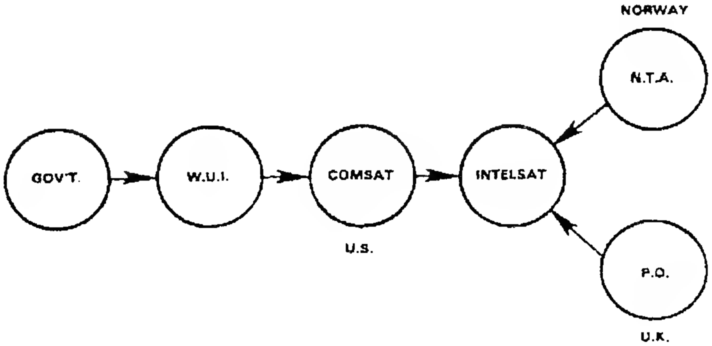

Fig. 2. MDHD Payment Flow

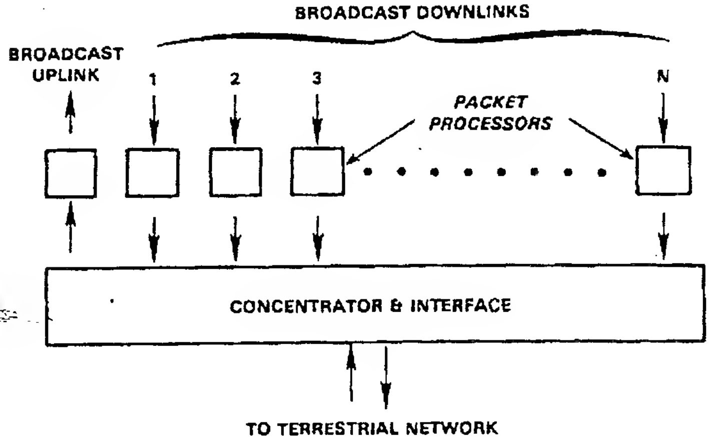

Fig. 3. Earth Station Configuration for Multiple Broadcast Channels in a High Capacity System