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**20/30 GHZ SATELLITE SYSTEMS
TECHNOLOGY NEEDS ASSESSMENT**

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ABSTRACT

NASA is involved in exploring the potential of the 20/30 GHz bands as evidenced by the propagation work in the ATS series by NASA-Goddard and, more recently, by the systems and market effort by NASA-Lewis. This paper focuses on the system and market work done by NASA-Lewis. Included are results of previous contractual and in-house studies, as well as preliminary results of on-going market and system studies. Baseline concepts for evaluating technology needs are also included.

INTRODUCTION

A forecast of U.S. domestic demand for satellite telecommunication services has been made which projects an annual growth rate of 15 percent (1). Various other forecasts have been made (2, 3, 4) indicating a potential need for very large numbers of transponders in the Region 2 orbital arc. Depending on service growth, these forecasts range from several hundred to more than a thousand transponders. If these forecasts are plausible, this growth will place a critical demand on orbit/spectrum resources since these resources are limited at C-band and Ku-band. This situation is further complicated by the projected growth in international traffic (5).

Currently, in the U.S., this development of satellite capacity is in the formative stages with C-band CONUS coverage satellites being used exclusively. These systems have already proven to be very cost-effective for the delivery of long-haul and wideband services. Partly due to the C-band success and partly due to the desire to eliminate the terrestrial tails, Ku-band satellite service will be offered commercially in a direct-to-user concept in the early 80's (1).

As the orbit becomes more crowded, it will, it is believed, become necessary to use advanced frequency re-use techniques and new frequency bands to satisfy the anticipated demand. Multiple spot beam spacecraft with the allocated bandwidth being re-used several times per spacecraft are believed to be the best approach to provide sufficient orbit space and spectrum to meet anticipated needs. However, large factors of frequency re-use will require very large spacecraft antennas if the spacecraft are designed with C-band technology. Table I compares the spacecraft antenna size requirements for various bands and number of spot beams. It can be seen that for large numbers of spot beams C-band does not compare favorably since it requires a large deployable antenna. Ku-band is the next most favorable, according to required antenna size. For this band, even the 50 beam antenna is small enough to fit within the shuttle envelope. This is especially critical since large focal length diameter ratios will be required to achieve good spot isolation in these systems (6). Based on size alone, 20 GHz appears the most favorable, with the size for a 50 spot beam antenna being in a range suitable for lens technology. A second consideration is the bandwidth available in the various bands. The allocation at 20 GHz is approximately a factor of 5 larger than either Ku-band or C-band. Combining this with the frequency re-use attainable with the multi-beam technology leads one to conclude that the 20 GHz band offers a tremendous spectrum resource, more than adequate to meet anticipated demands. Unfortu-

nately, the rain attenuation is significantly greater at 20 GHz and especially so for the 30 GHz uplink. Therefore, there are many questions relative to reliability and viability to be answered and much technology to be developed at this band before commercial implementation will occur.

PREVIOUS NASA EFFORTS IN 20/30 GHZ BANDS

NASA has been involved for some time in the evaluation of the potential for 20/30 GHz satellite communications. The first activity was the propagation work done by NASA-Goddard with the ATS-5 and ATS-6 satellites. This work is documented elsewhere (7) and will not be covered here.

Recently, NASA has initiated a series of millimeter wave (20-80 GHz) system and market studies to further evaluate the potential of the millimeter bands as measured against forecasted market needs (3, 4, 8). Early in this effort, it became apparent that the rain attenuation expected throughout these bands would significantly affect system design (3). However, it was not clear how this attenuation would affect the cost-effectiveness of such systems since cost is affected by system capacity and the capacity is expected to be very large relative to today's C-band systems. Also, it was not clear how to fully utilize this expected capacity and, without high utilization, the economy-of-scale effect would not be realizable. Therefore, since the attenuation in the MM bands was least at Ka-band, an effort was directed at estimating rain attenuation in the 20/30 GHz bands and the resultant impact on system user costs. This was done for a variety of system concepts assuming the systems were fully utilized. The under-utilized case can be obtained simply by multiplying the user cost by an appropriate factor.

To put the following discussion in perspective, consider the quality of service offered to users of communications systems. Table II shows overall reliabilities offered by various systems as well as specific reliability against rain alone. Excellent reliability is clearly available with conventional terrestrial and C-band satellite systems. SBS, however, is seeking a body of users who are willing to sacrifice some reliability in order to realize other advantages. For the 20/30 GHz band, viable services with high reliabilities will require new concepts in systems implementation otherwise this band will only be suitable for those users and services where rain outage is not of major concern.

For purposes of discussion, consider early estimates of rain attenuation as shown in Figure 1 (3). Note that curves are shown for single terminal sites as well as sites which have dual terminals (site diversity). The second terminal makes use of the reduced correlation of rain fades between separate terminals and achieves a specified reliability with significantly less margin. An example will illustrate this point. For the SBS system, a 1.5 dB margin is selected on the downlink to yield a rain reliability of 99.6 percent. On the uplink, a 5 dB margin is selected to yield a rain reliability of 99.9 percent for an overall rain reliability of 99.5 percent. For single terminal sites at 20/30 GHz, the same reliability levels would require 5.5 dB of margin on the downlink and in excess of 20 dB on the uplink. As the reliability increases from 99.5 percent, the required margin increases drastically. With diversity at 20/30 GHz, only 1.3 dB would be required on the downlink and only 3.5 dB on the uplink. The impact of these selections is compared for several systems having CONUS coverage in Table III. Note that the S/C RF power requirement is affected by a rise in ground terminal noise temperature as well as increased attenuation. The high power requirements aboard the spacecraft and the ground terminal raise questions as to the viability of 20/30 GHz service to single-terminal sites. However, the case with diversity appears attractive even with CONUS coverage. But, due to the attendant costs of dual terminals at each site, a unique user is required who has sufficient traffic to justify the added expense.

Since the most dense traffic occurs on long line trunks interconnecting major metropolitan areas, long line trunking appears to be a natural application of high capacity 20/30 GHz satellites. Indeed, there would be sufficient traffic to justify site diversity and the added expense. The problem, of course, is how to integrate the satellite system with existing communication facilities - especially facilities that have significant remaining life. It is assumed herein that such an integration is feasible - perhaps the satellite would be used for dynamic allocation of additional capacity and, therefore, augment rather than replace existing facilities.

For this trunking application, very narrow and independent spot beams could be used to advantage to reduce the required spacecraft power as well as the earth station G/T and transmitted power.

Such systems have been considered and one typical configuration is shown in Figure 2 (B). In this particular case, six beams are used to achieve 6X frequency re-use for the equivalent of 90,000 duplex voice circuits.

Estimates of the added charge per voice channel for the satellite routing have been made and the results of the service costs are given in Table IV as a function of the number of beams. The basis for this charge includes the costs of an on-orbit, as well as ground spare, launch costs for two satellites, operation and maintenance, and the earth station costs. The service costs are arrived at by assuming an 8-year life for the spacecraft, 14-year life for the earth stations, a 10 percent discount rate and a fully utilized satellite. This service cost does not account for actual satellite utilization or any required terrestrial tails. However, multiplying these costs by a factor of four, to account for less than full utilization, results in charges that are still significantly lower than today's rates. All these data were computed for an overall rain reliability of 99.9 percent. The sensitivity of these charges to changes in rain reliability is indicated in Table V. Note that an increase in overall rain reliability to 99.97 percent results in a 50 percent increase in user charge. However, the rate is still relatively low even if escalated by the previous factor of four.

Larger systems such as would include direct-to-user applications were evaluated in the NASA-Lewis in-house studies. Figure 3 shows one typical system making use of many spot beams to achieve 22 times frequency re-use. This particular configuration assumes the use of 9 spots per cell before frequency re-use and assumes the indicated interferences are sufficiently isolated to achieve about 30 dB C/I ratios. Costing for these direct-to-user systems was not done in these preliminary studies but is being done as part of on-going contractual efforts which include direct-to-user as well as trunking applications as discussed in the next section. With the larger systems, it became apparent that TDMA is most appropriate while, for the smaller systems, FDMA has a clear advantage. These early efforts suggested the need for certain technologies which are shown in Figure 4.

For the space segment, it is believed that high-gain multiple-beam antennas employing extensive frequency re-use are essential to insure an adequate spectrum resource beyond the year 2000. For these large systems, it is also believed that high-speed baseband processing is necessary to achieve the most efficient utilization of the spacecraft. However, in the formative stages, RF or IF switching will probably suffice. It is also believed that wideband multimode spacecraft transmitters will also be required to dynamically provide for rain margins and allow for a large number of signals per transmitter.

For the ground segment, it is believed that multimode transmitters will also be needed as well as significant advances in high speed/high capacity buffers.

For both the space segment and ground segment, there will be a need for high speed processors to enable the demand access function.

CURRENT EFFORTS IN 20-30 GHZ BANDS

As a follow-on to these preliminary studies, NASA-Lewis has embarked on a series of system and market studies to evaluate concepts and test their relevancy against forecasted market needs. Currently, four contractual efforts are underway - two parallel system studies by two satellite system suppliers and two parallel market studies by two common carriers. These efforts are specifically designed to elicit the needs of the carriers and the capabilities of the suppliers by having them actively involved in the definition of technology needs. The flow of this effort and the interaction is outlined in Figure 5. Ford Aerospace and Hughes Aircraft are performing independent system studies while ITT and Western Union are performing independent market studies. Mid-way through this 9-month effort,

all contractors will provide a joint briefing to NASA-Lewis and other invited government and industry representatives. During this review, it is expected that all participants will be made aware of both the technical and market potential of these bands. A similar interaction at the final review is expected to result in a concurrence of what form the final satellite system is likely to be, what the enabling technologies are, and what form the precursor system ought to be.

A schematic of the technical portion of these studies is shown in Figure 6. Both FDMA and TDMA systems are considered with both direct-to-user (as in SBS) and trunking applications included in each. Also, for each of these cases, the impact of on-board spacecraft switching will be evaluated. In addition to developing a catalog of viable systems, this approach will provide an indication of the best trunking configuration as well as the best direct-to-user configuration.

In order to focus the technical effort, it was necessary to select initial concepts to consider. Table VI compares the direct-to-user and trunking applications as well as the configurations to be evaluated for each. In addition, variations on certain parameters are to be evaluated such as number of spot beams and offered rain reliability. These variations will provide information on sensitivity of the nominal configurations and also will be beneficial to the market effort in that it provides a means of aiding the elicitation of user sensitivities to service cost and service quality.

Underlying the system analyses will be certain assumptions regarding the market including rain reliability and satellite utilization. The market effort will address these assumptions by forecasting market demand and evaluating user requirements for reliability. An outline of this market effort is shown in Figure 7.

A demand forecast for the 1980-2000 time frame is to be provided according to service type and to user category. This latter element is needed to evaluate requirements for rain reliability. A case study will be performed to provide both a typical market for planning purposes and a validation of analysis techniques.

In addition to these studies, another effort by Mitre Corporation is evaluating generic on-board processing concepts. This is an independent effort but is expected to provide significant supporting background data for the aforementioned technical studies.

SUMMARY AND CONCLUSIONS

The 20/30 GHz bands appear attractive economically and with certain technology advances appear to offer a virtually unlimited spectrum resource. This attractiveness is especially relevant to high density trunking where there is sufficient traffic to justify dual-station site-diversity. On-going system and market studies actively involve satellite system suppliers and carriers as well as the government in a cooperative, mutually beneficial effort. It is believed that this is the approach most likely to result in a spectrum efficient, acceptable risk, high capacity 20/30 GHz satellite system which is relevant to anticipated markets.

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TABLE I. - COMPARISON OF ANTENNA SIZES

NUMBER OF BEAMS	4 GHz DIAMETER METERS	12 GHz DIAMETER METERS	20 GHz DIAMETER METERS
10	2.0	0.7	0.4
25	5.0	1.7	1.0
50	7.1	2.4	1.4
100	10.0	3.3	2.0

TABLE II. - TYPICAL RELIABILITIES OFFERED TO USERS

SCOPE OF RELIABILITY	SYSTEM USED	RELIABILITY PER CENT
TOTAL	INTELSAT	99.95
	CROSS-COUNTRY MW	99.98
RAIN ONLY	SBS	99.6 DOWNLINK 99.9 UPLINK

TABLE III. - COMPARISON OF CONUS COVERAGE SYSTEMS HAVING 5 METER EARTH STATIONS

FREQUENCY SIZE	DIVERSITY	GROUND T_e °K	SKY CONT, °K	DOWNLINK MARGIN, dB	UPLINK MARGIN, dB	TRANSPONDER POWER WATTS	TERMINAL POWER Kw
14/12	N	146	79	1.5	5.0	20	4
30/20	N	200	194	5.5	>20	90	>125
30/20	Y	200	70	1.3	3.5	23	2.8

TABLE IV. - ESTIMATED COSTS FOR 20/30 GHZ TRUNKING SYSTEM

[Cost variation with number of ground sites for a rain reliability of 99.9.]

# * GROUND SITES	DOWNLINK FREQUENCY GHZ	GND. ANT. SIZE, M	GROUND COST \$M	SAT. COST \$M	SAT. WT. LBS.	LAUNCH COST (VEH)/COST	DUPLEX CAPACITY	MONTHLY ** COST/DUPLEX LINK, \$
2	20	6.23	11.30	10.55	1877	(AC)/15.1	30,000	59.2
4		4.89	21.45	11.44	2104	(AC)/15.1	60,000	34.7
6		4.31	31.76	11.81	2090	(AC)/15.1	90,000	26.2
8		3.96	41.63	12.35	2200	(AC)/15.1	120,000	21.9
10		3.69	51.87	12.61	2334	(IUS)/25.9	150,000	21.2

*Two terminals per site (two-station diversity).

** Assumes 3 satellites, one on-orbit spare, one ground spare and full utilization of one satellite. Price would be approximately a factor of 4 higher based on costing of current DOMSAT systems in FCC filings and published rates.

TABLE V. - ESTIMATED COSTS FOR 20/30 GHZ TRUNKING SYSTEM HAVING SIX BEAMS

[Variation with rain reliability.]

RAIN * RELIAB. %	DOWNLINK FREQUENCY	GROUND COST, \$M	SAT. COST, \$M	SAT. WT. LBS.	LAUNCH COST (VEH)/COST	DUPLEX CAPACITY	MONTHLY ** COST/DUPLEX LINK, \$
99.0	20/30	30.3	10.8	1914	(AC)/15.1	90,000	24.95
99.9		31.8	11.8	2090	(AC)/15.1	90,000	26.16
99.97		32.7	13.6	2400	(IUS)/25.9	90,000	33.70

*Two-station diversity.

** Assumes 3 satellites, one on-orbit spare, one ground spare and full utilization of one satellite. Price would be approximately a factor of 4 higher based on costing of current DOMSAT systems in FCC filings and published rates.

TABLE VI. - BASELINE SYSTEM CONCEPT STUDY REQUIREMENTS

PARAMETER	DIRECT-TO-USER	TRUNKING
Communications Mode	SCPC FDMA, TDMA, SS-TDMA	FDMA, SS-FDMA, TDMA, SS-TDMA
Stations	10,000	10
Spot beams	25	10
Proportion reliability, %	99.5, power margin only	99.9, power margin or diversity
Station interconnects	40 KHz to 40 MHz, 40 kbps to 40 Mbps	200 MHz or 200 Mbps
Service Assignment	Demand assignment	Preassignment
Link performance	Analog: TBD S/N Digital: 10 ⁻⁶ BER, QPSK	Analog: TBD S/N Digital: 10 ⁻⁶ BER, QPSK
Coverage area	U.S.	U.S.
Space transportation system	Shuttle and SSUS or IUS	Shuttle and SSUS or IUS

EFFECT OF RAIN RELIABILITY ON RAIN MARGIN

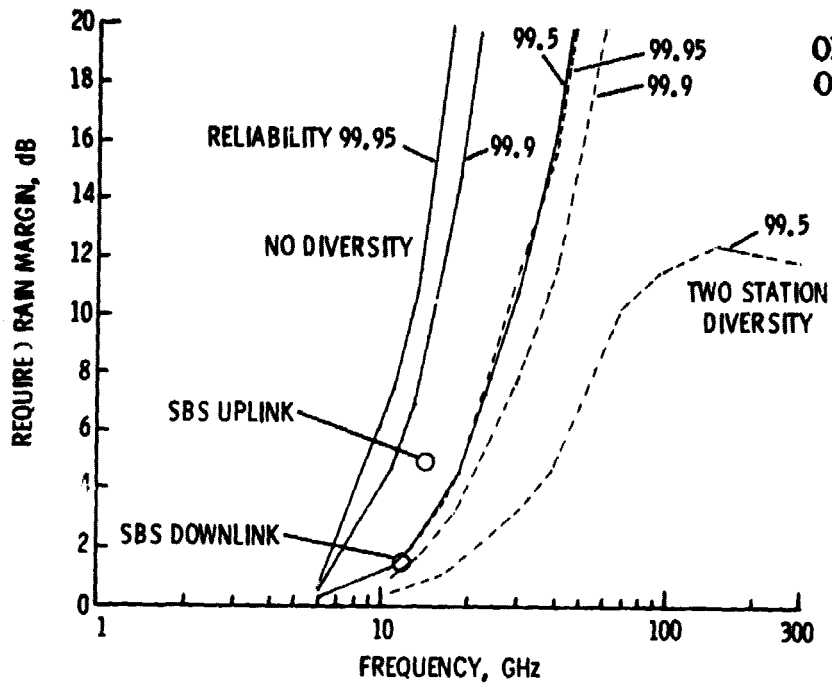


Figure 1. - Estimates of rain attenuation.

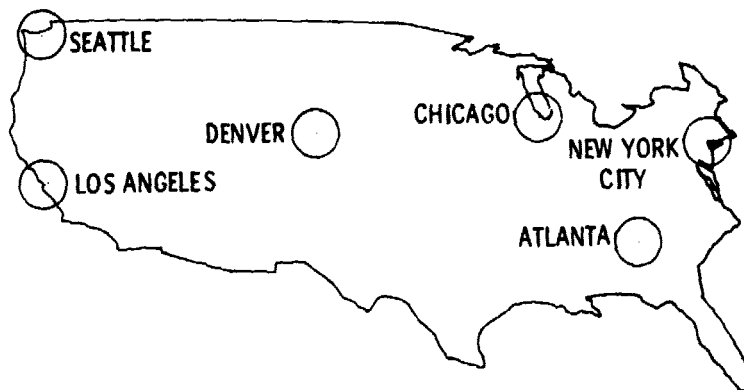


Figure 2. - A minimum 20/30 GHz network concept.

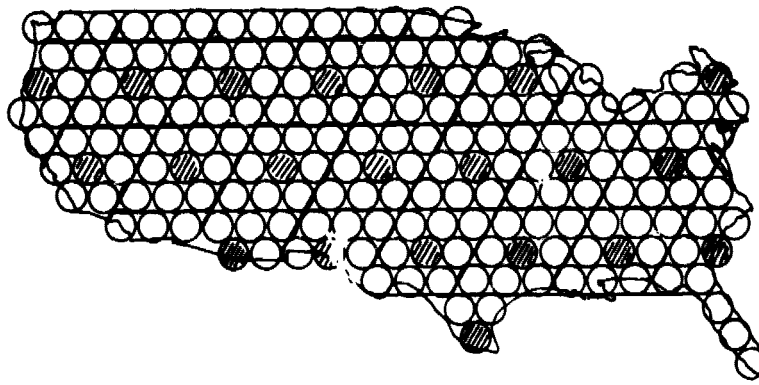


Figure 3. - Typical large scale 20/30 GHz network with 22 times frequency re-use.

FIGURE 4

18/30 GHz FIXED SERVICE SATELLITE PROGRAM
ENABLING TECHNOLOGY

SPACE SEGMENT

- MULTI-BEAM ANTENNA
 - HIGH GAIN SPOT BEAMS
 - EXTENSIVE FREQUENCY RE-USE
- ON-BOARD SATELLITE SWITCHING
 - HIGH SPEED (< 0.5 USEC)
 - SWITCHING AT RF OR IF
 - MULTIPLE ACCESS
- TRANSMITTER/TRANSPONDER
 - MULTI-LEVEL POWER
 - WIDE BANDWIDTH (≤ 1.0 GHz)

GROUND SEGMENT

- TRANSMITTER
 - MULTI-LEVEL POWER
- HIGH SPEED/HIGH CAPACITY BUFFERS
- MULTIPLE ACCESS HARDWARE

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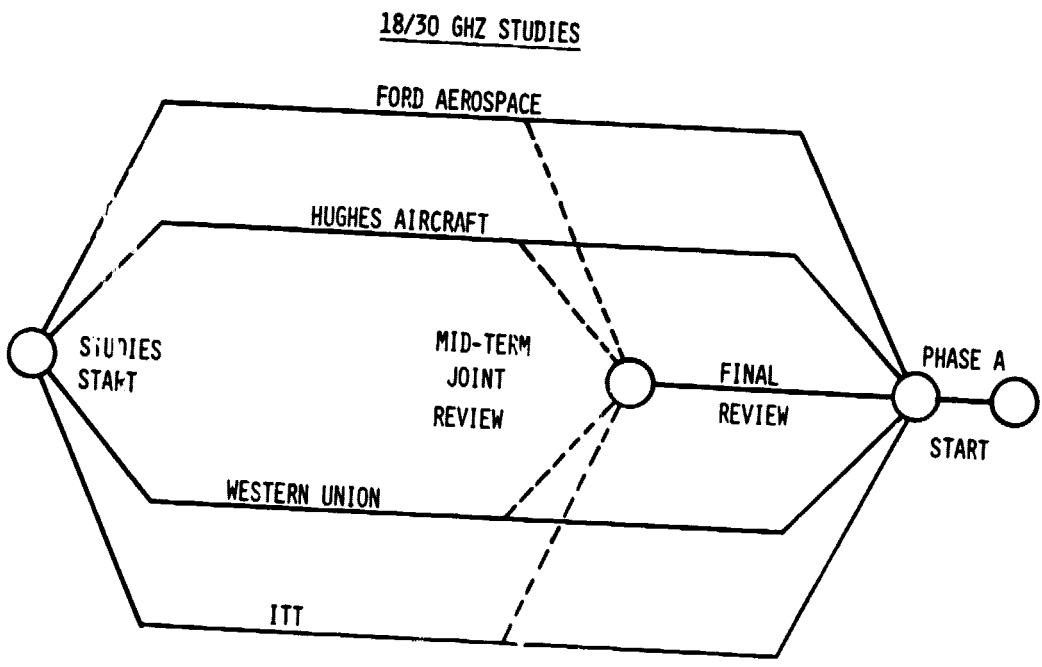


FIGURE 5

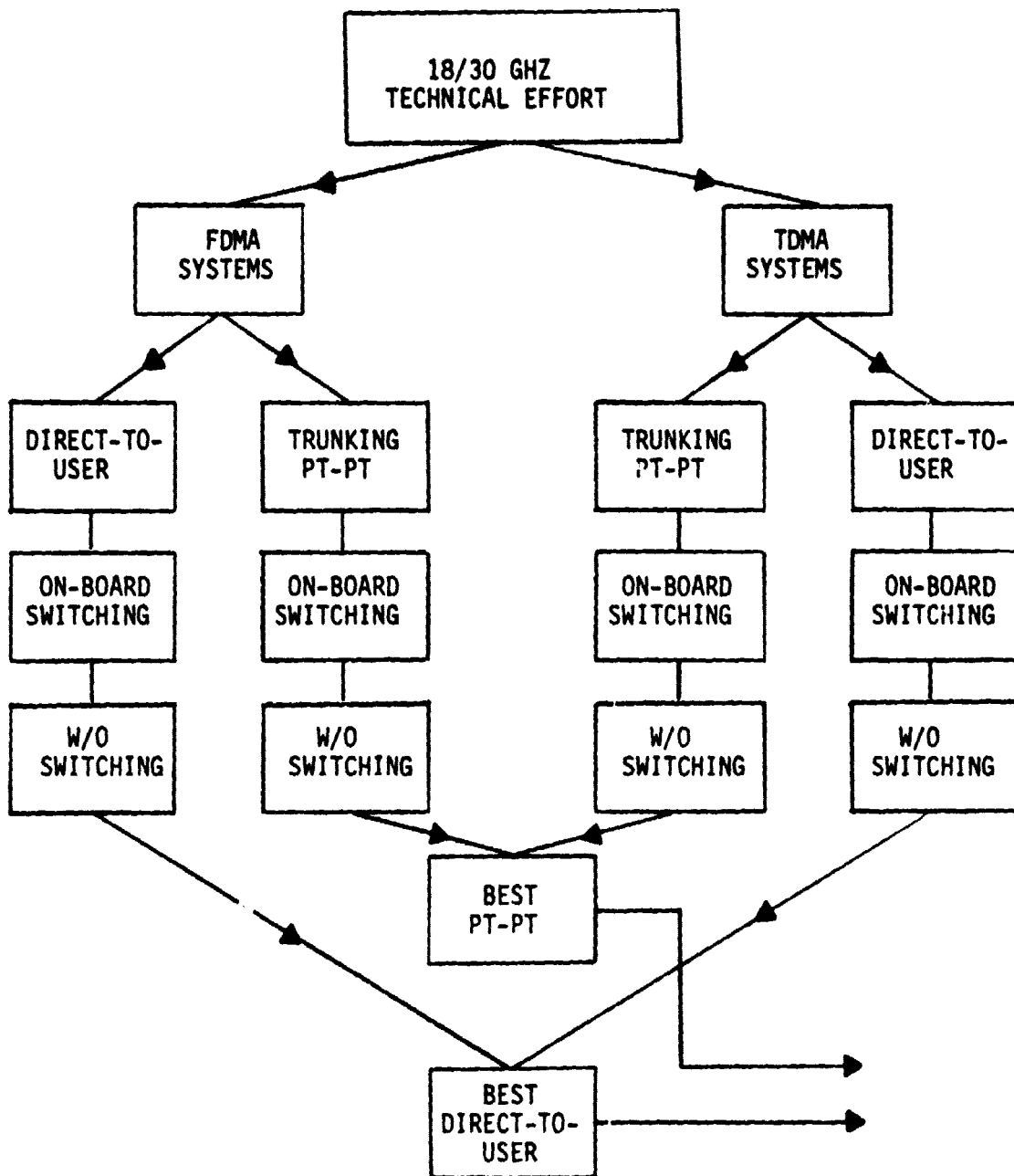


FIGURE 6

18/30 GHZ MARKET STUDY

- TASK 1 - Literature Survey
- TASK 2 - Demand Forecasts for Telecommunication Services for the Period 1980-2000
 - A. Telecommunication Service Demand
 - B. Distance Distribution of Traffic
 - C. Traffic Volume as a Function of City Size
 - D. Geographical Distribution of Traffic Volumes
 - E. Sensitivity of Service Demand to Variations in Service Cost
- TASK 3 - User Market Identification
 - A. Traffic Forecast by User Category
 - B. Relative Size of Each User
 - C. Demographics of User Categories
- TASK 4 - Case Study of the Communications Traffic Demand Within A Metropolitan Area
- TASK 5 - Present and Projected and C and Ku-Band Satellite Service Costs
 - A. Satellite and Terrestrial Projected Service Costs As Function of Distance
 - B. Terrestrial Tail Costs
 - C. Maximum Volume of C and Ku-Band Satellite Service
- TASK 6 - 18/30 GHz Communications Service Demand Forecasts
 - A. Service Demand As A Function of Reliability
 - B. Real Time Versus Non-Real Time Service Demand Forecasts
 - C. Traffic Suited for 18/30 GHz Systems

FIGURE 7