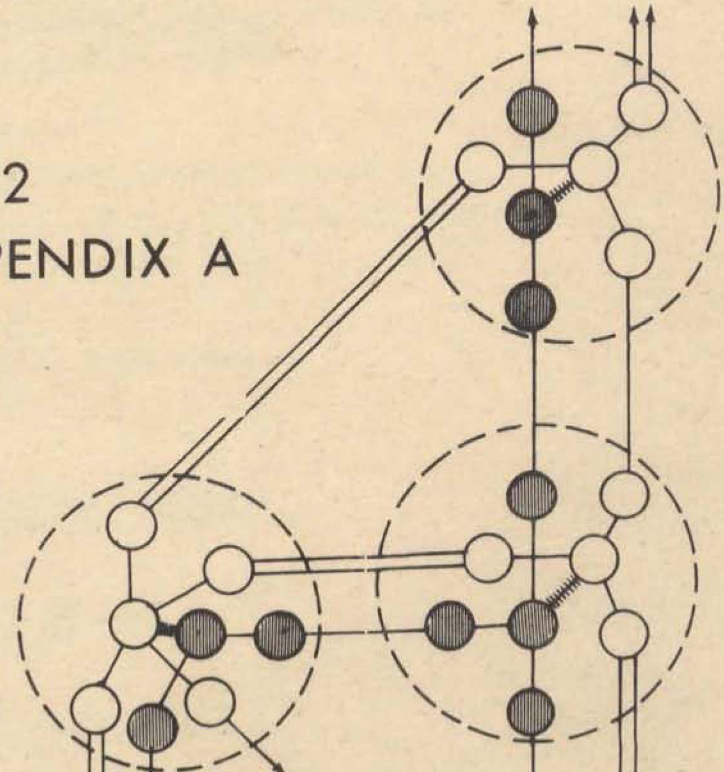
Communications Research Centre

DOMESTIC LONG DISTANCE COMMUNICATIONS NETWORK STUDY

VOLUME 2
FULL REPORT-APPENDIX A



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OTTAWA, JUNE 1975

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COMMUNICATIONS RESEARCH CENTRE

DEPARTMENT OF COMMUNICATIONS
CANADA

DOMESTIC LONG DISTANCE COMMUNICATIONS NETWORK STUDY
VOLUME 2 – FULL REPORT – APPENDIX A

by

Communications Systems Research and Development Staff

R.V. Baser, R.R. Bowen, R.L. Hutchison, A.R. Kaye, T.A.J. Keefer, G.A. Neufeld,
J.L. Thomas, E.A. Walker, P.R. Whalen

(Technology and Systems Branch)

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THE PROJECT TEAM

Rather than attributing authorship of the component parts of this report we have chosen to describe the roles of the various people who have contributed to the project as well as to the writing of the report. Three people have been part of the project from start to finish and have contributed to almost every part of it: Dr. A.R. Kaye (Project Leader), Dr. R.R. Bowen and Dr. G.A. Neufeld. Dr. T.A.J. Keefer was solely responsible for the forecasting of voice circuit requirements. E.A. Walker and R.L. Hutchison contributed to the development of the terrestrial network model and J.L. Thomas to the satellite models. R.V. Baser and P.R. Whalen did a great deal of the computer programming and production work involved in the study.

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DOMESTIC LONG DISTANCE COMMUNICATIONS NETWORK STUDY

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ABSTRACT

The most cost-effective satellite system for the Canadian domestic long-haul network are Anik-like satellites in the early 1980's and satellites similar to the RCA Globcom satellite in the late 1980's and early 1990's. In a minimum-total-cost network three such satellites would be placed in orbit. However, if present institutional arrangements continu throughout the next decade it is likely that only two such satellites would be used. The present value in 1980 of the extra cost of the latter development would be about ten millio 1973 dollars.

The present 4 GHz and 6 GHz analog microwave radio systems and the proposed 8 GHz digital overbuild on the TCTS microwave radio system are expected to meet Canadian terrestr long-haul requirements throughout the 1980's and early 1990's. At that time one or more of the four following options likely will be implemented

1) conversion of 4 GHz and 6 GHz systems to digital use,

2) construction of a new 12 GHz digital radio system,

3) overbuilding of the existing 4 GHz radio system with a 6 GHz system,

4) construction of a digital long-haul optic fibre system.

Such systems may be required sooner in the Toronto-Montreal corridor.

Résumé

Les systèmes de satellites ayant le meilleur rendement-coût pour le réseau national interurbain du Canada sont les satellites du genre Anik pour le début des années 1980 et les satellites semblables au satellite RCA Globcom pour la fin des années 1980 et le début des années 1990. Dans un réseau à coût total minimal trois satellites de chaque genre seraient placés en orbite. Toutefois, si les arrangements institutionnels qui existent Présentement ne changent pas d'ici à l année 1990, restaient inchangés jusqu'en 1990, il est probable que seulement deux satellites de chaque genre seraient utilisés. La valeur présente en 1980 du coût additionel pour un développement ultérieur serait d'environ dix millions de dollars 1973.

Le réseau hertzien analogue à 4 GHz et 6 GHz et l'addition d'un système de transmissior numérique à 8 GHz sur le réseau de transmission par micro-ondes du R.T.T. devraient satisfai les besoins du réseau interurbain terrestre du Canada jusqu'au début des années 1990. A ce moment-cà, une ou plusieurs des quartres options suivantes seront vraisemblablement adoptées:

1) la conversion des systèmes analogues à 4 GHz et 6 GHz pour utilisation numérique.

2) la construction d'un nouveau système de radiocommunication numérique à 12 GHz.

3) l'addition d'un système de radiocommunication à 6 GHz sur le système de radiocommunication à 4 GHz.

4) la construction d'un système de transmission numérique interurban pas fibre optique.

De tels systèmes seront peut-être requis plus tôt pour le corridor Toronto-Montréal.

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CHAPTER 1

INTRODUCTION

1.1 TERMS OF REFERENCE OF THE STUDY

In December 1972, Communication Systems Engineering (now Communication Systems Research and Development) was called upon to assist the Planning Branch in a project to be called the Domestic Long Distance Communication Network Study (DLDCNS). The study is concerned with the requirements for heavy-route long-distance transmission facilities in Canada in the 1980's and the operational and economic impact that advanced satellite systems will have upon the network which will provide these requirements. Its broad objectives were stated to be:

a) to determine how satellite communications can best fit into a mix of terrestrial and satellite facilities for providing long distance trunk facilities;

b) to develop an appreciation of the economic and network planning factors involved in the provision of long distance trunk facilities; and

c) to recommend policies that would result in an orderly development of satellite facilities for the greatest national benefit in the long term.

The role of Communication Systems Engineering was to conduct engineering/economic studies related to these objectives. Thus we were able to take objectives (a) and (b) as our own without change, but objective (c) had to be modified; we shall not recommend policies but rather we shall review that range of options which, in our opinion, best meet the criteria specified.

Objective (b) is clear enough but objectives (a) and (c) hinge on words and phrases such as "best", "orderly development", "greatest national benefit in the long term" and "long-distance" which require elucidation. Since our study was to include forecasting of requirements we took "greatest national benefit" to mean "meet the forecast requirements with a reliable network while providing flexibility to accommodate variations from the forecasts". "In the long term" means post-1980 for our purposes since no policies adopted in 1975 or later can have any significant effect on the national long-distance network before

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that date. Furthermore the first ANIK satellite system will require replacement by approximately 1980. "Orderly development" we take to imply that there should be smooth transitions from each generation of technology to the next. There remains the definition of the word "best". For our purposes we took it to mean minimum direct expenditure, on a national basis to achieve the greatest national benefit as defined above. Since the starting point of our study is 1980 we shall take account of expenditures incurred after 1979 only and in order to measure the value of a time-stream of expenditures we shall use its present value.

Direct expenditures include capital costs, and costs of maintenance, operation and minor technological upgrading. Thus we do not include such items as corporation taxes and corporate profits. Neither do we concern ourselves about the ownership of the various elements of the network or the financial arrangements between carriers, all of which would have a very considerable effect on a study of this nature if it were being conducted by a carrier. Thus our point of view differs considerably from that of the carriers; it also differs from that of any particular consumer of telecommunication services since we do not consider tarriffs. Our point of view is essentially that of the collectivity of all telecommunications consumers, since a national network requiring minimum direct expenditures would also provide the basis for minimum overall tarriff structures.

Finally it was necessary to decide upon the interpretation of the term "long-distance". One of the major objectives of the study is to determine the cross-impact of satellite and terrestrial elements of the network. Furthermore we are concerned with heavy-route facilities. Thus there is no point in including in our study any distances which are so short that there can be no question that a terrestrial system should be used. This means that we should include routes over about 200 miles where there is substantial traffic.

1.2 SCOPE AND STRUCTURE OF THE REPORT

During the course of the study we produced a total of fifteen reports containing detailed descriptions of various aspects of the work. The titles of these earlier reports are:

1. Outline of the Long Distance Network Study and its Reporting Procedures

2. Forecasting Traffic Requirements

3. Forecasting Total Voice Circuit Requirements

4. Updated Forecasts of Total Interprovincial Voice Circuit Requirements

5. Traffic Capacities and Costs of Terrestrial Facilities Associated with a Satellite of the Anik Type using Digital Modulation Techniques

6. An Initial Estimate of Requirements for a Domestic Trunk Communications Satellite System in the 1980's

7. Forecasting Intra-Provincial Voice Circuit Requirements

8. The Network Optimization Technique Used in the Domestic Long-Distance Communications Network Study

9. Earth Segment Capital Costs

10. Computer Program For Determining Satellite Costs

11. A Simplified Model of the Canadian Terrestrial Trunk Communications Network

12. Computer Program Development for the Long Distance Network Study

13. Scenarios to be Investigated and Revised Television Traffic Forecasts

14. An Applied Graph Theoretic Approach to Network Synthesis for Long-Distance Communications

15. SYN: A Computer Program For Long-Range Network Planning

The information in some of these reports has been superseded by that contained in this report. In other cases the salient features and many of the details are included in this report or its appendices. Where necessary the reader is referred to an earlier report for additional details. The purpose of this final report is to offer the reader all the information he needs for an understanding of the results that were achieved and the background and methods with which they were achieved.

The study itself was split into three major divisions: preliminary studies to assemble, construct and model a sufficient information base, preliminary studies to develop the methods and tools required to generate results and finally the synthesis of

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the results themselves. The report is divided along similar lines; Chapter 2 summarizes the results of the preliminary studies concerned with the information base while Chapter 3 discusses the methods we developed and the various assumptions we had to make in order to generate results. In Chapter 4 we present our conclusions including the range of options. We identified several as being optimal while others, which we evaluated and found to be sub-optimal, are also discussed. Since our conclusions were established on the basis of the methods and assumptions described in Chapter 3 it was necessary to investigate the degree of sensitivity to them. Where significant sensitivity was discovered, it is discussed in presenting the results in Chapter 4. In other cases, where variation of a paramenter of assumption resulted in very little or no change in the results, the appropriate sensitivity analysis is presented in Appendix E.

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CHAPTER 2

INFORMATION BASE DEVELOPMENT AND MODELLING

Since the study is concerned with the interactive effect of terrestrial and satellite services in the total national environment, it was necessary to develop an information base on all systems which are, or could be, used for long-distance transmission on the existing national network or its expansion. Since the terrestrial systems are a larger and more complex than the satellite systems a large part of the early studies was devoted to investigating them. In addition, it was necessary to forecast requirements for such facilities over the time frame of the study. A number of preliminary studies were undertaken for these purposes; they are described in this chapter.

2.1 EXISTING TERRESTRIAL TECHNOLOGIES AND SYSTEMS

The currently existing Canadian long-distance communication networks are based almost entirely on microwave radio operating in the 4 GHz band in the case of the trans-Canada Telephone System (TCTS) and the 6 GHz band in the case of Canadian National/Canadian Pacific Telecommunications (CN/CP).

Information on the extent and content of these networks was obtained from the Radio Regulations branch of DOC. Their data base lists every radio repeater site in the country and specifies the installed equipment. This information was sufficient to identify routes and determine the installed capacity on them.

Information on the new capital cost of microwave equipment had been gathered in a prior study (reference 9) and was supplemented by new information on both capital and maintenance and operation (M&O) costs. Each of four different classes of repeater in both the 4 GHz and the 6 GHz frequency bands was modelled by a non-linear function of equivalent new capital cost versus capacity. Details of these results are presented in Appendix B.

A separate study enabled satellite ground stations and their back-haul facilities to be modelled also by functions of capital cost versus capacity and information was gathered on M&O costs. Any specific satellite has a fixed capability at launch which cannot be modified during its life, and a cost which normally includes provision of an in-orbit back-up satellite and a second back-up satellite on the ground. It also requires the use of terrestrial telemetry, tracking and control (TT&C) facilities which represent essentially the operating cost of a satellite system. Information on all these costs was obtained for current generation systems (see Appendix C).

2.2 NEW TECHNOLOGIES

New technologies are being developed for both terrestrial and satellite use. A special study was devoted to a forecast of their probable technological characteristics and costs. Detailed information on this activity is contained in Appendix B for terrestrial systems and in Appendices C and D for satellite systems. A summary is given below.

Coaxial cable systems have never been extensively used for long-distance communications in Canada because of their relatively high cost compared with microwave radio, especially in the pre-Cambrian shield and mountainous areas, and because our population density is low compared with the areas of the U.S.A. and Europe where cables are used. New, higher capacity, coaxial cable systems operating in both analog and digital modes will be commercially available by 1980. Analog and digital coaxial cable systems will be comparable in cost and capacity. In Canada it seems unlikely that they will be used in the 1980's, except in the high-traffic-density Toronto-to-Quebec corridor, for the same reasons as in the past. Since building of a digital system, LD-4, has already been started on the Toronto-Ottawa-Montreal route it is unlikely that any other long-distance coaxial cable system will be introduced in the 1980's. The capacity of LD-4 and similar systems will range from about 20,000 to 40,000 vouce circuits, depending on the number of coaxial pairs in each cable. The cost is expected to be in the range $3.60 to $4.85 per voice-circuit mile at full capacity.

Millimetre waveguide systems, using digital transmission, are being developed in several countries and are expected to be available by the early 1980's. No reliable cost information could be found but the capacity of such systems is so large, about 240,000 voice circuits, that there is little likelihood that they would be economically viable in Canada in the 1980's.

Optic fibre systems for long-distance application are not likely to be commercially available before the late 1990's. No cost information on complete, installed systems is as yet available.

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Medium capacity digital microwave radio systems will be available from Canadian sources by 1980. They will have a capacity of about 13,000 voice circuits and will be cheap to implement because they can be added onto the existing 4 GHz structures. Thus the full-load average cost should be about $2.00 per voice circuit mile. Higher capacity digital radio systems operating at 12, 15 or 20 GHz will be probably available from non-Canadian sources by the mid 1980's. Their capacities will be in excess of 30,000 voice circuits with fully loaded costs in the vicinity of $2.35 per voice circuit mile.

2.3 A MODEL OF THE NATIONAL NETWORK

The national network of long-distance transmission systems was modelled by a mathematical network of nodes and links. The links represent point-to-point transmission systems and a function of capital cost versus capacity is associated with each link. It was essential to keep the number of primary nodes in the model to a minimum in order to avoid excessive complexity and difficulty in later stages of the study. A geographical location is therefore included as a primary node in the model if it meets one or more of the following criteria:

i) it is a major population centre or the "centre of gravity" of a major populated area,

ii) it is a CBC regional centre, or

iii) it is a major junction of terrestrial long haul facilities (for instance the Sudbury-North Bay area).

The resulting set of nodes, together with the major terrestrial routes connecting them are shown in Fig. 2.1. Each route may be represented by several parallel links in the actual model. Secondary nodes were added later at potential ground station sites and for various other reasons associated with the detailed modelling process. Links were included in the model to represent all existing long-distance systems and all potential systems using either current technology or new technologies which were determined to be feasible and reasonably cost-effective by our study of new technologies.

Where, in the physical network, long-distance and short haul systems share common sites or structures the cost/capacity function associated with the corresponding link in the model has been carefully designed to take the sharing into account with costs allocated on a pro rata basis in terms of capacity. The network model was constructed in such a way that the separate identities of the existing terrestrial networks of the TCTS and CN/CP were retained.

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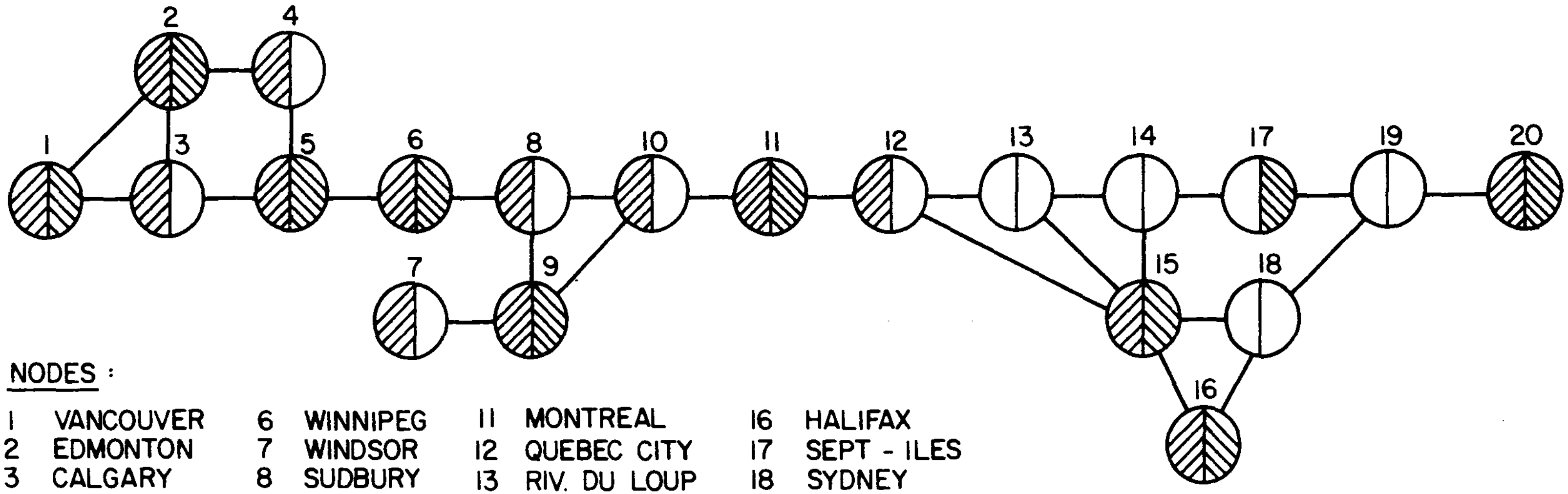

NODES:

1	VANCOUVER	6	WINNIPEG	11	MONTREAL	16	HALIFAX
2	EDMONTON	7	WINDSOR	12	QUEBEC CITY	17	SEPT - ILES
3	CALGARY	8	SUDBURY	13	RIV. DU LOUP	18	SYDNEY
4	SASKATOON	9	TORONTO	14	RIV. BLANCHE	19	CORNERBROOK
5	REGINA	10	OTTAWA	15	MONCTON	20	ST. JOHN'S

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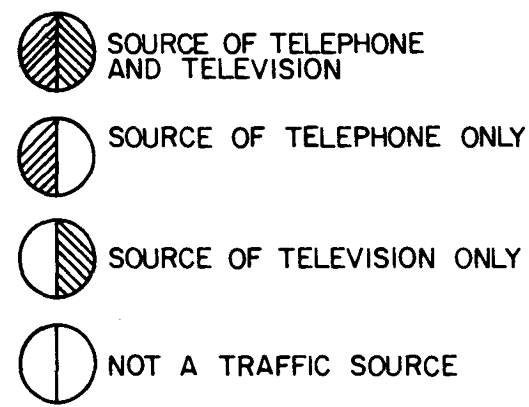

FIGURE 2.1

SOURCES OF TRAFFIC IN THE SIMPLIFIED NETWORK

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The model of the terrestrial and satellite portions of the network are described in detail in Appendices B and C respectively.

2.4 CONVERSION TO DIGITAL TRANSMISSION IN TCTS

The TCTS is the major carrier of switched message traffic in Canada and is likely to remain so. It has made a firm decision to convert progressively from analog to digital transmission and switching for reasons of overall network efficiency, economy and flexibility. The conversion program is already underway but will increase in momentum about 1978-1980. After 1980 it is unlikely that any major new analog systems, or expansions of existing systems, will be built within the TCTS. This means that growth in requirements in the 1980's will be accommodated primarily by means of medium capacity digital microwave radio systems sharing the existing 4 GHz analog microwave ratio structures or by satellite facilities. In the very high density Toronto-Ottawa-Montreal-Quebec corridor, larger systems such as the coaxial LD-4 system or perhaps, later, high capacity digital radio will be used. These factors have been taken into account by including separately identified digital and analog sections of the network model.

Because the CN/CP network is mainly non-switched there is less incentive for it to convert to digital transmission.

2.5 FORECASTS OF REQUIREMENTS

Forecasts of long-distance transmission capacity requirements between the nodes shown hatched in Fig. 2.1 were made for two classes of traffic: public switched telephone, leased lines data and other message traffic constitutes one class and television channels the other. Forecasts of this nature are always subject to wide confidence limits and this was accentuated in our case by the very limited data available to us. To indicate this uncertainty the forecasts are expressed in terms of maximum, preferred and minimum values for each class of traffic and each of the years 1980, 1985 and 1990.

The forecasts are discussed in detail and tabulated in Appendix A which also includes an estimate of 1973 requirements.

As well, estimates were made of the thin-route voice requirements and the television requirements in the Arctic and between Arctic communities and southern Canada. These are also presented in Appendix A.

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CHAPTER 3

METHODS AND ASSUMPTIONS

3.1 INTRODUCTION

The objectives of the study and a general review of the approach used in the study were presented in the first chapter. In this chapter we discuss the framework in which the study was done. This includes a discussion of the assumptions that were made and of their significance in the results.

Our objective in this study was not to give a detailed and rigid blue print for network evolution through the 1980's. In view of the uncertainty inherent in any traffic forecast looking ahead 10-15 years this would not be possible. Rather, our intent was to identify those broad options which have the greatest potential for cost-effectiveness while also being sufficiently flexible that they could later be adapted to the actual as opposed to the forecast traffic growth.

In chapter four, the evolution of the network which has minimum cost, subject to several non-economic constraints, is described. A discussion of what we assume to be the constraints on the choices for network evolution are presented in section 3.2. These constraints include:

i) The necessity for a smooth network evolution,

ii) The assumption that the present division of traffic between TCTS and CNCP will not undergo major change, and that Telesat Canada will remain a carrier's carrier;

iii) The assumption that the present requirements on the quality of signal transmission will continue, and that the requirements for survivability of the network will increase;

iv) The requirement that the radio spectrum be used wisely.

A brief description of how the minimum-cost network was determined is presented in section 3.3. That section includes discussion of:

[redacted]

i) what is meant by a minimum-cost network;

ii) how the cost of systems which may be included in the network were determined;

iii) how these systems were combined to form a minimum-cost network, subject to the constraints described in section 3.2. (A more detailed description of this methodology is presented in Appendix F.)

3.2 ASSUMED CONSTRAINTS ON NETWORK EVOLUTION

3.2.1 SMOOTH EVOLUTION OF THE NETWORK

The communications network being considered in this report is that which would best meet Canada's needs in the 1980's. Primarily, we are concerned with the 1980 to 1987 interval, because that is the approximate interval of the next operational satellite system in Canada. However, it is also necessary to consider the time-frame 1987 to 1994 in which a third operational satellite system will be used, and also to consider the earlier 1975 to 1980 period in which the present network will undergo its initial expansion.

Potential networks for the 1980-87 period are compared by evaluating the present value (in 1980) of the costs of these networks in the 1980's. (This evaluation is discussed in more detail below in section 3.3). However, much of the network in 1987 will be usable in the late 1980's and early 1990's. Thus there is a cost penalty in choosing a network for 1980-87 which cannot easily be expanded to meet requirements in the 1990's. To account for this requirement, the larger 1980-94 interval was used in determining the present value of network costs. An even longer period of time was not considered because of the increasing variance of estimates as one predicts further into the future, and because of the diminishing importance of expenditures, due to the discounting of future costs.

The immediate future, 1975 to 1980, presents a different compatibility problem. Any expansion in the 1980's must be compatible with the network in 1980. The probable expansion of the network in the next five years must be taken into account to ensure continuous reliable service and to avoid large conversion costs in 1980. The present study is not concerned directly with expansion in the 1975-80 interval; such expansion is already too far into the planning stage for such a study to have an effect. However, the network in 1980 must be estimated as a base point

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from which to consider later expansion. It is assumed that the network in 1980 will have the following characteristics:

i) After 1980 any expansion of the TCTS terrestrial transmission network will be with digital systems such as the LD-4 coaxial cable or a digital radio system, rather than by continued expansion of the 4 GHz analog system;

ii) CN/CP will continue to expand their 6 GHz analog radio system;

iii) the TCTS routing hierarchy will evolve from a 5 level one to a 3 level one in the late 1970's and early 1980's, with each of the traffic-generating nodes of the DLDCNS network model being a high level node in the new TCTS network;

iv) the present Anik satellite system will not carry voice traffic in southern Canada, except for greater use of the existing Toronto-to-Vancouver link.

Because of (i), all expansion of the TCTS network in the 1980's is assumed to be by digital means. Because of (iii), the existing 5 level TCTS routing hierarchy was ignored in favour of the expected new 3 level hierarchy. All voice-traffic-generating nodes in the TCTS network are expected to be high level nodes in the new hierarchy, so hierarchial routing considerations were ignored. The lower-level local hierarchial structures were taken into account in determining the voice-traffic matrices of Appendix A.

3.2.2 RELATIONSHIPS AMONG THE CARRIERS

We assume that the present situation with respect to competition in the long-distance network will persist into the future without substantial change. Thus the networks of TCTS and CN/CP Tel. are assumed to develop separately with a division of traffic essentially as at present. Telesat Canada is assumed to act as a carrier's carrier and either TCTS or CN/CP Tel. traffic or both may be routed by satellite facilities wherever it is cost-effective to do so. (Note that in our study the cost-effectiveness of routing traffic terrestrially or by satellite is not based on inter-company leasing rates, but on basic costs. The implications of this distinction are discussed in chapter 5.) In order to study such a scenario it is necessary to make some assumptions regarding the portions of the total long-distance traffic which will be carried by the two carriers on a cost-effective basis as described above. The assumption we

[redacted]

have made is that the present division of traffic will not change substantially in the future. The result of this assumption is a division according to the following table:

Message Traffic (including private line, telex and data)	84% TCTS	16% CN/CP
CBC TV circuits	TCTS	
All other TV	CN/CP	

This assumption preserves the status quo quite rigidly with respect to message traffic but places no constraint on the trade-offs between satellite and terrestrial systems. The relative proportions of television traffic carried by the two carriers will however depend upon the relative growth of CBC traffic and all other television traffic. In principle this uncertainty could introduce rather arbitrary trends in network development but in fact, as will appear from the results which are presented in the remainder of the report, this does not occur because the bulk of television traffic is routed via satellite facilities so that it is immaterial whether it is derived from the TCTS or the CN/CP network.

3.2.3 NETWORK SIGNAL-QUALITY REQUIREMENTS

It is assumed that the signal-quality requirements for the transmission of voice and television will remain much the same as at present. However, there are several new transmission media becoming available that have considerably different subjective distortion characteristics. It is assumed that:

i) use of digital transmission and encoding equipment such as DITEC is adequate for transmission of CBC, CTV, and Global TV programs;

ii) use of 64 Kb/s PCM digital transmission combined with source encoding equipment such as SPEC is adequate for long-haul voice transmission;

iii) the 0.27 second transmission delay in single-hop transmission through a satellite link is acceptable for long-haul voice transmission in southern Canada.

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3.2.4 NETWORK SURVIVABILITY REQUIREMENTS

Network survivability is the ability of the network to carry traffic in the event of a catastrophic failure such as the destruction of a microwave repeater site or the failure of a complete satellite while in orbit. This is distinct from the protection of a system against loss of services due to the failure of an amplifier or fading of a single radio channel. Protection against that type of failure is provided for by installing spare radio channels or coaxial tubes on hot standby, and using these channels within milliseconds of the failure of an operational channel. However, this gives no protection by itself against the catastrophic failure of a complete system. This is done by routing traffic through other branches of the network as soon as the failure is detected. Since the Canadian terrestrial networks are essentially chain networks with small subnetworks at various places (see Fig. 4.3 and 4.4), protection is provided by installing two or more parallel systems on a given branch of the network, and by routing all the traffic through these parallel systems in the event of a system failure. In such a situation all the hot-standby radio channels would be used to carry traffic.

A measure of network survivability is the percentage of the original voice circuits on a given branch are working after a system catastrophic failure. For instance, if a given branch were equipped with two parallel systems, each with five working and one standby radio channels, the network survivability of that branch would be 60%. Most of the TCTS network has 50% to 60% survivability at the present time; a notable exception is the single terrestrial link from Cornerbrook to St. John's. We anticipate that, with network expansion to meet additional traffic requirements in the late 1970's and early 1980's, the network survivability will be increased to about 70% or 75% throughout the TCTS network except for the link into St. John's, and to 50% on that link. This is consistent with published TCTS plans.

The conventional network survivability specifications, such as those discussed in reference 6, do not consider how a satellite should be integrated into the overall network from a network survivability viewpoint. Because of the lack of either specification or precedent in a network in which the satellite system is economically competitive, the following specification is proposed for the Canadian network and was used in this study:

i) It was assumed that not more than 50% of all voice circuits passing through any one network cross-section could be through the satellite if 3 identical operational satellites were in orbit, or

[redacted]

more than 33 1/3% if 2 satellites were in orbit. (Variations of this specification are investigated in section 4.6.3).

ii) No terrestrial backup is assumed to be required for network television signals which are routed through the satellite.

Other specifications of course are possible. The effect on the network growth and cost as a result of adopting another specification is investigated in chapter 4.

3.2.5 USE OF THE RADIO SPECTRUM

It is assumed that present ITU and DOC regulations on the use of the microwave radio spectrum continue into the 1980's. In particular, it is assumed that:

i) the 700 MHz wide band from 3.5 GHz to 4.2 GHz will be available for analog terrestrial transmission by TCTS;

ii) the 3.700 to 4.200 GHz and 5.925 to 6.425 GHz bands will be available for satellite systems, but with the present constraints on flux-density of radiation from the satellite;

iii) the 500 MHz wide band between 5.925 GHz and 6.425 GHz will continue to be available to CN/CP, and also to TCTS if interference with CN/CP systems can be avoided;

iv) the 500 MHz wide band from 7.725 GHz to 8.275 GHz, excluding the band from 7.975 to 8.025 GHz, will be used for medium capacity digital terrestrial radio transmission;

v) the 500 MHz bands from 11.7 GHz to 12.2 GHz and from 14.0 GHz to 14.5 GHz will be used primarily for either voice or video transmission through a satellite, and that there will be no limitation on the flux-density of transmission from the satellite.

These are likely to be the only frequency bands required for long-haul transmission in the 1980's, as will be shown in chapter 4.

In the 1990's these bands may haye to be augmented by bands at 12 GHz and/or 14 GHz for high capacity digital terrestrial transmission and by use of the 2.5 GHz wide band at 18 GHz and 30 GHz for satellite transmission.

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3.3 DETERMINATION OF THE MOST COST-EFFECTIVE NETWORK EVOLUTION

The most cost-effective network is that network which meets the traffic requirements at minimum total cost, subject to the constraints discussed above in section 3.2. There are several problems associated with this method of choosing a network evolution. They are:

i) a description of what is meant by a "minimum cost network" must be made very carefully;

ii) the network requirements cannot be predicted exactly, because these predictions are based on a very limited data-base of past traffic, and because requirements as much as fifteen years into the future must be considered;

iii) the costs of the various systems which may be part of the total network cannot be determined exactly.

Estimation of the network traffic requirements is made in Appendix A. A description of what is meant by a minimum cost network is given in section 3.3.1. A brief description of how this network is determined is given in section 3.3.2. An important "input" to the network optimization discussed in section 3.3.2 is the cost of each potential node and link in the network. Evaluation of these costs is discussed in section 3.3.4.

3.3.1 A MINIMUM-COST NETWORK

As discussed in section 3.2.1, we wish to determine the network which meets the communication requirements of the 1980's at minimum total cost, taking into account the cost of money. Any new facilities installed in the 1980's augment or replace facilities which are installed before 1980. Thus the viewpoint taken in this study is that of determining what new facilities should be installed in the 1980's to augment the "existing" network in 1980, such that the present value of total network costs incurred in the 1980-94 time-frame is minimized.

We wish to determine, then, what network augmentation in the 1980's results in minimum total expenditure of national resources in the 1980's. To do this, the only costs which we consider are the amortization costs of new equipment installed in the 1980's, and the maintenance and operations (M+O) cost of equipment in use in the 1980's. Only M+O costs are included for

[redacted]

equipment which was installed before 1980 but used in the 1980's; since it is now too late to have any effect on network capital expenditures before 1980, we do not include the cost of unretired debt on these expenditures. Considered from a different viewpoint, such costs are common to any augmented network, and so do not influence the choice of options for network augmentation after 1980. Neither do we include such "costs" as corporate profit, corporate income taxes, municipal land taxes, etc., as they are not an expenditure of national resources.

3.3.2 METHODOLOGY USED TO DETERMINE THE MINIMUM-COST NETWORKS

The basic methodology used to determine the most cost-effective network for the 1980's was to:

i) develop a model of the network which includes all important nodes and links in the TCTS and CNCP networks, and also includes the satellite system and any potential satellite ground stations in southern Canada;

ii) determine the cost of each of the links and nodes in that network model as a function of traffic through the node or link;

iii) route traffic through the network, and hence determine required link capacities, in such a way that the total network cost is minimized.

Development of the network model and description of the terrestrial network costs are given in Appendix B. A description of the capabilities and costs of potential satellite systems is given in Appendix C. The methodology used to optimize the network is described in more detail in Appendix F.

There are a large number of possible networks that need to be considered in order to select the network with minimum present value. It is impractical to determine the present value of each one. A practical approach, which we use, is to select the more economically attractive networks by comparing their annual costs at specific times within the period of analysis (1980's). We then determine the present value of this much smaller number of relatively economical networks. Finally, we select the network with minimum present value.

There is a factor that has considerable influence on the evolution of the network if it is desired to minimize the total present value of that network. That is, services must be provided to the many small communities in the Arctic and sub-Arctic by satellite. These services include distribution of live CBC television programs and connection into the Canada-wide telephone network. It is assumed that the services provided in the north by the Anik satellite system will be continued and expanded in the 1980's. (note that provision of these services to the many small communities would be much more costly by a terrestrial microwave radio network). Because of the above consideration, there is sure to be a satellite system of some type in the overall Canadian network in the 1980's. Thus the problem becomes one of determining how much of the television and voice traffic in southern Canada should be carried on the satellite system.

The problem of minimizing the total network cost thus becomes one of augmenting the transmission capacity of either a terrestrial system or the satellite system such that the marginal cost of the total network is minimized. It is the marginal cost of adding capacity to a system that is of interest, then, rather than the average cost of a voice circuit or video channel through that system. Use of the former results in minimum total network cost; use of the latter does not.

It is especially important to make this distinction between average costs and marginal costs when considering the satellite system. The use of marginal costs results in a much different network, and a less costly one, than that which would result if average costing were used because of the nonlinear relationship between satellite capacity and costs, primarily because of a large number of satellite options. This is especially important when one considers that the present rate structure for the Anik satellite system is based on average costs. The problem of rate assignment for a network that is designed on a marginal-cost basis is not investigated in this report. Rather, we are concerned with the network evolution at minimum total network cost; the use of marginal costs is a means to that end.

3.3.3 DEPENDENCE OF NETWORK COST OF INFLATION RATE AND ON THE COST OF MONEY

While inflation will affect the cost of future systems, its significance in our study is low because we are trading off or comparing the cost effectiveness of different systems. Forecasting differential rates of inflation for the various cost components of communications systems is always complex and virtually impossible in the present unsettled economic conditions. In any case, improvements in technology frequently have more effect than inflation. Thus we assumed all costs to remain constant in 1973 dollars except for technological improvements which are already foreseen and which are now in the advanced or exploratory development stage.

The appropriate level of the discount rate to be used for the economic evaluation of alternatives in the study received considerable attention. Certainly the opportunity cost of capital should be at least as great as risk free constant dollar interest rates being paid by say long-term government bonds. A discount rate of 10% was used in the study. This figure can be justified by examining the current cost of capital to private firms in the industry. This rate is also being used by others such as Intelsat for the Intelsat V study, the Ministry of Transport in analysis of the Mirabel airport complex, and in urban renewal projects. Finally, and most significantly, sensitivity analyses on the discount rate have shown that our results are not dependent upon variation of the discount rate.

3.3.4 EVALUATION OF NETWORK LINK COSTS

As discussed above in section 3.3.2, evaluation of the cost of each link of the network as a function of the traffic through that link is an important step in the selection of the most cost-effective network. Evaluation of the costs of terrestrial systems is described below in section 3.3.4.1, and the evaluation of satellite system costs is described in section 3.3.4.2. It should be noted that the cost of equipment which would be common to any network augmentation, such as multiplex and switching equipment, is not included.

3.3.4.1 TERRESTRIAL SYSTEM COSTS

The total capital costs of existing radio systems connecting pairs of nodes in the network were obtained in terms of their present replacement value and were based on the costs of the individual repeater sites that are in the field. The total capital cost is diminished by the proportion of local traffic through the individual repeater sites so that the costs used in the network model reflect only those costs for long-haul traffic. For new terrestrial systems, the capital costs are based on cost/repeater where the system would use existing structures. Otherwise they are based on an average cost/mile, taking into account a factor for detours in the actual route. The details of the terrestrial model and its costs are described in Appendix B.

We need to convert the capital costs of systems to annual costs to carry out the comparison of the large number of possible networks and select its most economical networks, as discussed in Section 3.2.

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If the amount of traffic carried on a system as a function of time over its complete lifetime is known, then there are methods to convert capital costs to annual costs. However, we do not have the data pertaining to the installation date of existing systems, and for the future, the traffic carried on any system as a function of time is a result of the study, rather than an input. Thus we had to use a different method for determining annual costs. The method we use is to assume that amortization costs, refurbishment costs, and maintenance and operation costs, which together form the total annual cost, are together a fixed percentage of the total capital costs. For annual maintenance and operation costs, expressed as a percent of total capital costs, we used 13% for radio systems and 10% for cable and waveguide systems. For the annual refurbishment cost of electronic equipment, expressed as a percent of total capital cost of electronic equipment, we used 5.7%. To determine the annual cost of amortization, we used 25 years as the lifetime of the initial portions of a system such as the land, building, roads, cables, antennas, and we used 15 years as the lifetime of the electronics of a system. As discussed in Section 3.2 above, we used 10% as the rate of interest in determining the annual cost of amortization. In general, as discussed above, the resulting annual cost is expressed as a function of the total installed capacity of the system. The annual cost of each system is nonlinear in that there is an initial cost plus a linear incremental cost. During the initial stages of analysis, much more complex highly nonlinear costs were used. However we found that there was little to be gained by this approach and, more important, they were accurate beyond reason in view of the accuracy of other factors such as traffic forecasts and local traffic. The reader is referred to Appendix B for a detailed description of the total capital costs of terrestrial systems and of the method used to determine annual costs from capital costs.

The cost of the network metropolitan junctions were determined in a manner similar to that of terrestrial systems. However, whereas the costs representing terrestrial systems which connect pairs of nodes in the network were nonlinear, the costs representing metropolitan junctions were linear. The reader is referred to Appendix B for a more detailed description.

The reader is referred to Appendix E for a discussion of the sensitivity analysis performed by varying the cost of terrestrial systems.

[redacted]

3.3.4.2 SATELLITE SYSTEM COSTS

The costs of satellite ground stations were determined in a manner similar to that used to determine the costs of terrestrial systems which have been described in the previous section. The capital cost of ground stations that we used take into account the cost of the land, building, antenna, prime power system, electronic equipment, and any backhaul facility. The total capital cost will, of course, vary depending upon such factors as the size of the antenna and the frequency band used. One of the objectives was to determine the types of ground stations to be used in the Canadian network.

The capital costs of ground stations were converted to annual costs by assuming that costs such as amortization and maintenance and operation are a fixed percentage of the total capital costs as was the case for terrestrial systems. For maintenance and operation costs, expressed as a percent of the total capital costs, we used 13%. To determine the annual cost of amortization, we used 15 years as the lifetime of a ground station. For reasons discussed in Section 3.2, there was no need to take into account the unretired debt on the existing ANIK ground stations. We took into account the cost of amortization of augmenting or modifying the existing ground stations. New equipment might be required for an existing ground station in order to improve the antenna, increase its capacity, add new transmitters, etc. Amortization costs were attributed to all new ground stations.

To determine the capital cost of the satellites themselves, we took into account the cost of development, production, transportation of the satellites to the launch site, the launch, launch insurance, and the incentive charge by a manufacturer for a satellite operating successfully in orbit. To determine the annual cost of amortization, we used 7 years as the lifetime for satellites.

Also included in the space segment costs are the amortization, maintenance, and operation costs of the telemetry, tracking, and control (TTC) station and the satellite control centre. The TCC station is costed in the same way as an existing ground station, in that only maintenance and operation of the existing portion of the TTC station are charged. We used a lifetime of 14 years to amortize the cost of modifications, new equipment, or new facilities for the TTC station and the control centre.

An extensive description and discussion of satellite systems technology and costs is given in Appendix C.

CHAPTER 4

MINIMUM COST NETWORKS FOR THE 1980's

4.1 INTRODUCTION

The important results of the study are presented in this chapter. Augmentation of both the terrestrial microwave radio systems and the satellite system, in such a way that the present value of total network costs over the 1980 to 1994 is minimized, is described.

As discussed in chapter 3, the ideal way to consider evolution of the network, from an economic viewpoint, is to determine that network evolution which results in the minimum present value of network costs at some arbitrary date, say 1980. Rather than determine the present value of a large number of possible networks, these networks were first compared by determining their annual costs in 1980, 1985, and 1990, subject to the constraint that each network must be compatible with the network which proceeded it in time. As explained in chapter 3, marginal costing was used in these annual cost calculations. A large number of uneconomical networks were removed from contention by this simpler computation. The most attractive networks, based on these annual cost calculations, were then composed by determining the present value of their costs over the 1980 to 1994 interval.

One can make several preliminary statements about the form of the network in the 1980's. These are that:

i) the three trans-Canada microwave radio systems that form the backbone of the Canadian long-haul network at present will continue to operate throughout the 1980's, because such systems are required for overall network survivability;

ii) the 4 GHz microwave radio systems of TCTS will be augmented by an 8 GHz digital add-on radio system, as part of a general conversion by TCTS to a digital network;

iii) a satellite system is required to meet the requirements for television distribution and thin-route voice traffic in northern Canada.

[redacted]

If one ignores the problem of network survivability for the moment, then whether a particular voice or television traffic requirement in southern Canada is met by augmenting a terrestrial system, or a satellite system, depends on the relative marginal costs of increasing the two systems.

Because of the relatively large capacities of the terrestrial systems, the marginal cost of increasing the traffic on a terrestrial link is independent of the amount of traffic on that link, up to the capacity of two 4 GHz systems and two 8 GHz systems in parallel. However, the situation is much different when one considers transmission by satellite; the marginal cost of increasing traffic through the satellite by a given amount decreases quite significantly as the traffic increases, over the range of interest. Thus it is important to establish the capacity and cost of a basic satellite system to meet northern requirements, as a basis upon which to consider routing of southern traffic.

As a preliminary result, the satellite system which would be required for northern services only, and for northern services and southern national television, is described.

Following this, a brief description of cost-effective source-encoding techniques to use within the satellite system, and possibly in terrestrial systems, is given.

With these preliminary results established, the satellite systems which result in minimum-total-cost networks to meet the 1985 and 1990 preferred traffic forecasts are described and their costs specified. The loading of the TCTS and CNCP terrestrial networks in 1985 and 1990 is also specified. In this network scenario considerable voice traffic is carried on the satellite system. A present-value comparison of this network and one with no voice by satellite verifies the result that the satellite should carry significant amounts of long-haul voice traffic.

The possibility of adding a regional television distribution capability in southern Canada to the above satellite system is investigated in section 4.5. (This possibility was introduced in the latter stages of the study at the request of DG/TSP). The additional weight and cost of several satellite options to carry regional TV are presented. Choice of such system parameters such as operating frequency, satellite EIRP, ground station G/T, etc. for minimum total system cost are resolved. However, no network trade-off between satellite and terrestrial systems for regional TV distribution was done because no detailed model of the provincial microwave radio systems could be developed in the available time.

[redacted]

The results presented in sections 4.2, 4.4, and 4.5 are based on the assumption that the preferred traffic forecast is correct, and based on a specific choice of network survivability specifications. The effect of changes in these important factors on the choice of satellite system and on the loading of the terrestrial systems is analyzed in section 4.6.

An important result of the study is the most cost-effective use to be made of the 4/6 GHz and the 12/14 GHz band by a satellite system. The question of when the 12/14 GHz band should be introduced, and how it should be used, is resolved in section 4.7. The possibility of using separate satellite systems and different frequency bands for television distribution and for voice transmission is also investigated in section 4.7.

As stated earlier in this section, and in more detail in chapter 3, the use of average or fully-allocated costing, rather than marginal costing, does not result in a minimum-total-cost network. The type of satellite system that would evolve, and the costs of the network, if average costing were used, is discussed in section 4.8. It is important to understand the penalty associated with this average costing, because it represents reasonably well the situation that arises when each carrier, supplier, user, etc. optimizes his own position in a regulated environment similar to that which now exists.

4.2 SATELLITE SYSTEM TO PROVIDE NORTHERN SERVICES AND TO DISTRIBUTE NATIONWIDE TELEVISION PROGRAMS IN SOUTHERN CANADA

It is assumed that the types of services which are currently being supplied by the Anik system in the north will continue to be provided by any follow-on satellite system, and that the magnitude of these services will increase at a rate similar to the growth of services in the south. No terrestrial transmission system can provide these services to the many scattered northern communities at a cost comparable to that of the satellite system, so a satellite system will probably continue to provide these services.

In determining whether a given service in southern Canada should be routed on terrestrial or satellite links, the marginal cost of providing the service by satellite should be compared with the marginal cost of providing the same service by a terrestrial system. If we consider the nationwide distribution of CBC, CTV and Global TV programs in this way, the result is a strong cost difference in favour of distribution by satellite. One of the reasons behind this result is that some of the television signals will be transmitted from the satellite whether or not they are used in southern Canada.

The satellite systems to provide northern services only, and to provide both northern services and southern television distribution, are described below.

4.2.1 SATELLITE SYSTEMS TO PROVIDE NORTHERN REQUIREMENTS ONLY

The estimated requirements for northern thin-route voice and television distribution are described in Appendix A. These requirements for the preferred traffic forecast are summarized in Table 4.1. It is assumed that the satellite transponders which will be used to replace those of the Anik satellites will have similar salient characteristics, since the Anik system includes a large number of ground stations designed to work with an Anik satellite. These ground stations could be used in any follow-on system, and would require satellite transponders similar to those in Anik.

As shown in Table 4.1, seven to nine such transponders are required in the 1980-1985 period, and ten to twelve transponders by 1990.

A satellite such as the 8 transponder satellite being developed by American Satellite Corp. could meet the 1980 - 1985 requirements if a source encoding scheme such as DITEC were used. The annual cost of the space portion of such a system, including the T.T.&C. ground station annual costs, is estimated to be $9.6 million in 1973 dollars.

In the 1985 to 1990 period a satellite system similar to the present Anik system would be required. The annual cost of the space portion of such a system is approximately $10.5 million 1973 dollars. (The method by which these estimates were made is described in Appendix C).

These costs can be used as a base upon which the marginal costs to include more services on the satellite can be determined.

Table 4.1

Preferred Forecast of Satellite Requirements in North

Year	Number of Transponders for Thin-Route Voice	Number of TV Programs to and from South	Number of Northern Regional TV Programs	Total Number of Transponders	
				With DITEC	Without DITEC
1980	2	3	3	7	8
1985	3	3	3	8	9
1990	4	5	3	10	12

4.2.2 INCLUSION OF SOUTHERN NATIONWIDE TELEVISION DISTRIBUTION SERVICES

The expected requirements for nationwide television distribution in southern Canada during the 1980's are discussed in detail in Appendix A. The number of Anik-like transponders to meet this need with a satellite system, in addition to meeting the northern services discussed in the previous section, is shown in Table 4.2. It is assumed that Anik-like transponders with about 5 watts output and 36 MHz useful bandwidth, feeding an antenna with a Canada-wide beam, will be used, since a large number of ground stations, especially in northern Canada, are equipped to use this type of system.

An augmented Anik satellite would adequately meet the combined northern requirements and southern TV requirements until 1985. If a system such as DITEC were not used, the satellite should be capable of having all twelve of its transponders in use for its full lifetime, i.e. extra TWTA's would be installed as in the Intelsat IV system, and a larger prime power system would be included. Even so, one TV program would have to be routed terrestrially, and no extra capacity for other services would be available. A less costly solution would be to use the DITEC encoding technique extensively. The total annual cost of the space portion of this system, and the DITEC encoding equipment, is about $10.7 million 1973 dollars. This is only about $1.1 million more than the space portion of the satellite system for northern services only.

Two possibilities are available to meet the 1990 requirements shown on Table 4.2. One possibility is to use two operational small satellites such as those of American Satellite Corp., with a third satellite in orbit as a spare and a fourth on the ground. The other possibility is to use a single operational satellite of the RCA-type with an in-orbit spare and spare on the ground. The first possibility requires extensive use of DITEC and use of ground stations with two antenna systems in southern Canada. However, it is a more reliable system in that the satellite system has an instantaneous 57% capability in the event of a satellite or ground station antenna failure, whereas the second system has no capability until the in-orbit spare satellite can be put into service.

The RCA-type satellite system is slightly less costly: its total annual costs are about $14.8 million in 1973 dollars. The additional cost of the dual operational satellite system is approximately equal to the annual costs of the additional antennas and DITEC equipment in the ground stations.

Table 4.2

Preferred Forecast of Satellite Requirements

for Northern Services and Southern Nationwide TV Distribution

Year	Use of DITEC	Number of Transponders Required		
		For Northern Services	For Southern TV distribution	Total
1980	Yes	7	1	8
1980	No	8	3	11
1985	Yes	8	2	10
1985	No	9	4	13
1990	Yes	10	4	14
1990	No	12	8	20

Adding the southern nationwide TV distribution to the satellite system's requirements results in a much less costly solution for the total network than if the television distribution in the south was by microwave radio. In 1985 the saving is approximately $8.1 million 1973 dollars annually, and in 1990 the saving is about $17.0 million 1973 dollars. Thus there is no doubt that nationwide TV programs in southern Canada should be distributed by satellite.

The next step is to consider the addition of southern high capacity and medium capacity voice traffic and southern regional television distribution to the satellite system. However, before these problems are considered the use of source encoding techniques such as SPEC and DITEC should be clarified. This is done briefly in the following section.

4.3 SOURCE ENCODING TECHNIQUES APPLICABLE IN A DIGITAL SATELLITE COMMUNICATIONS SYSTEM

Two digital source encoding techniques are being developed by COMSAT Laboratories for use in the Intelsat satellite systems. One is the Speech Predictive Encoded Communications (SPEC) system for voice transmission and the other is DITEC, a digital television communications system for satellite links. These systems can of course be used on a digital terrestrial system, but because of the significant end costs of these systems it would not be economical to do so unless the route lengths were quite long.

Estimates of the cost and performance of these systems were obtained from COMSAT. Based on these estimates, analysis showed that the use of SPEC and DITEC reduces significantly both the total cost and the spectrum used by a satellite system to carry a given amount of traffic. Thus the satellite system should be a digital one, and should use these encoding techniques, even though the terrestrial system or part of it is an analog one. This will be shown in more detail in Appendix D.

From a network viewpoint, DITEC and SPEC, or other similar systems, can be used to double the capacity of a digital satellite system at a much lower cost than the original system. Moreover, they can be introduced during the lifetime of a satellite system to increase its capacity. This is a considerable economic advantage, because of the high interest rates, and because a satellite system must be under-utilized in its first few years if it is to be large enough towards the end of its lifetime.

It should be noted that to the author's knowledge neither the television networks nor the common carriers have yet agreed to the use of these systems. However, field trials of both systems have been carried out successfully on Intelsat IV, and DITEC has been tested on the Anik system.

The salient features of these systems are described below.

4.3.1 THE DITEC SOURCE ENCODING SCHEME FOR TELEVISION

A digital television communications system for satellite links, DITEC, was developed by COMSAT so that two NTSC television signals could be transmitted with network quality through a single satellite transponder such as that used on Intelsat IV or Anik.

In the DITEC equipment a colour television signal is encoded digitally at a 29.4 Mb/s rate. A rate 7/8 convolutional channel encoder is then used to provide forward error correction. The transmitted rate is 33.6 Mb/s. With the channel encoding scheme in use, this 33.6 Mb/s can be transmitted over a channel with a 10^{-4} bit error rate and provide a network quality picture. When an error does occur which is not corrected, however, a complete line or part of a line on the picture is in error, rather than just the noise "spot" which occurs in a conventional system.

The capital cost of the DITEC equipment is $40,000 to $50,000 (1973 dollars) for either the encoder or the decoder. This amount may be reduced by either production of a large number of units or by evolution to a simple system, but the amount of this reduction is difficult to predict and so was not included in the costing of competitive networks.

If DITEC were used on the Anik system or a follow-on satellite with Anik-type transponders, four phase PSK could be used to transmit two CBC, CTV, or Global TV programs to or from the network television ground stations. This has been done over an Anik satellite link between Vancouver and Montreal.

4.3.2 THE SPEC SOURCE ENCODING SCHEME FOR VOICE

A <u>s</u>peech <u>p</u>redictive encoded <u>c</u>ommunications system, SPEC, has been developed by COMSAT to double the number of pulse-code-modulated voice channels through a given satellite system. Like TASI, an earlier voice encoding scheme for analog transmission systems, SPEC takes advantage of the fact that in a voice conversation between two people only one person is usually talking at once, and there are even gaps in that person's voice stream. Both SPEC and TASI use this unused capacity to transmit twice as many voice conversations as can be handled by a conventional system, and do it reliably by averaging the unused capacity over several tens of voice conversations.

A serious disadvantage of the earlier TASI system was that a voice signal was clipped when its volume became too low. This problem has been overcome in the SPEC system.

In its present form, SPEC has been designed to work within the European digital hierarchy. In the European digital networks 32 voice circuits are time-division multiplexed and transmitted at 2.048 Mb/s. The input to the SPEC equipment is two such 2.048 Mb/s bit streams, and its output is one such bit stream. This equipment has been tested successfully over an Intelsat IV link between Hawaii and the continental US.

COMSAT personnel have indicated that the equipment could be adapted to the North American digital network at either the 1.54 Mb/s T-1 rate or the 6.3 Mb/s T-2 rate, but that it would likely work better at the higher T-2 rate. The capital cost of the SPEC equipment is about $200 per voice-circuit-end.

These two source encoding systems, SPEC and DITEC, are expected to be able to lower the costs of both satellite and terrestrial systems, but especially satellite systems, by the 1980's.

4.4 MINIMUM-COST NETWORK FOR THE 1980's

The minimum-total-cost satellite-terrestrial network to provide the northern services described in section 4.2, national television distribution, and long-haul voice transmission is described in this section. The additional traffic considered here, over that considered in section 4.2.2, is voice and data transmission in southern Canada. Estimates of this traffic are described in Appendix A. The network to meet the 1985 and the 1990 preferred traffic estimates is described here.

The network synthesis was carried out based on the following assumptions:

i) All TCTS long-haul traffic growth after 1980 would be on a digital network. The 1980 traffic on the 4 GHz terrestrial network would continue to be carried by that network, but would not expand;

ii) A satellite system will be used to provide northern services whether or not the satellite is used in southern Canada;

iii)Not more than 50% of the voice traffic through any network cross-section can be carried by a satellite system with three orbiting satellites, nor more than 33 1/3% by a satellite system with two orbiting satellites.

iv)Source encoding techniques such as SPEC and DITEC will be used anywhere in the network where it is cost-effective to do so.

4.4.1 MINIMUM-COST NETWORK FOR THE EARLY 1980's

Based on the above assumptions and constraints, two possible evolutions of the network in the early 1980's have similar low cost. One of these possible networks includes a satellite system with three orbiting Anik-like satellites, two carrying traffic and one an in-orbit spare. It carries a total of 9,200 full-duplex voice circuits in Canada as well as the television and thin-route northern voice requirements discussed in section 4.2. The amount of voice traffic through the satellite is limited by the 50% survivability constraint across the Manitoba-Ontario border. The other system includes a satellite similar to that being built for RCA-Globcom (referred to below as an RCA-type satellite) and its in-orbit back-up. This satellite system carries 6,800 voice circuits in addition to the television and northern traffic discussed in section 4.2. The amount of voice traffic through the satellite is limited to 33 1/3% of the total voice traffic through the cross- sections shown in Fig. 4.1

An augmented RCA-type satellite, i.e, one with 24 operating transponders plus spare amplifiers, could be used to carry the same traffic as the two Anik-like satellites, including the 9200 voice circuits. Such a system would have a lower cost than the other two systems. However, it would result in a network with poor protection against catastrophic failure of the satellite system. Thus the choice is between the satellite system with 3 orbiting Anik- like satellites carrying up to 50% of the voice traffic, and that with 2 orbiting RCA-type satellites carrying a maximum of 33% of the voice traffic.

The salient features of the two contending systems are shown in Table 4.3. Also included is the RCA-type satellite system with heavier voice-circuit loading for comparison purposes. As shown, the network with the RCA-type satellite, loaded to acceptable limits, costs approximately $0.4 million per

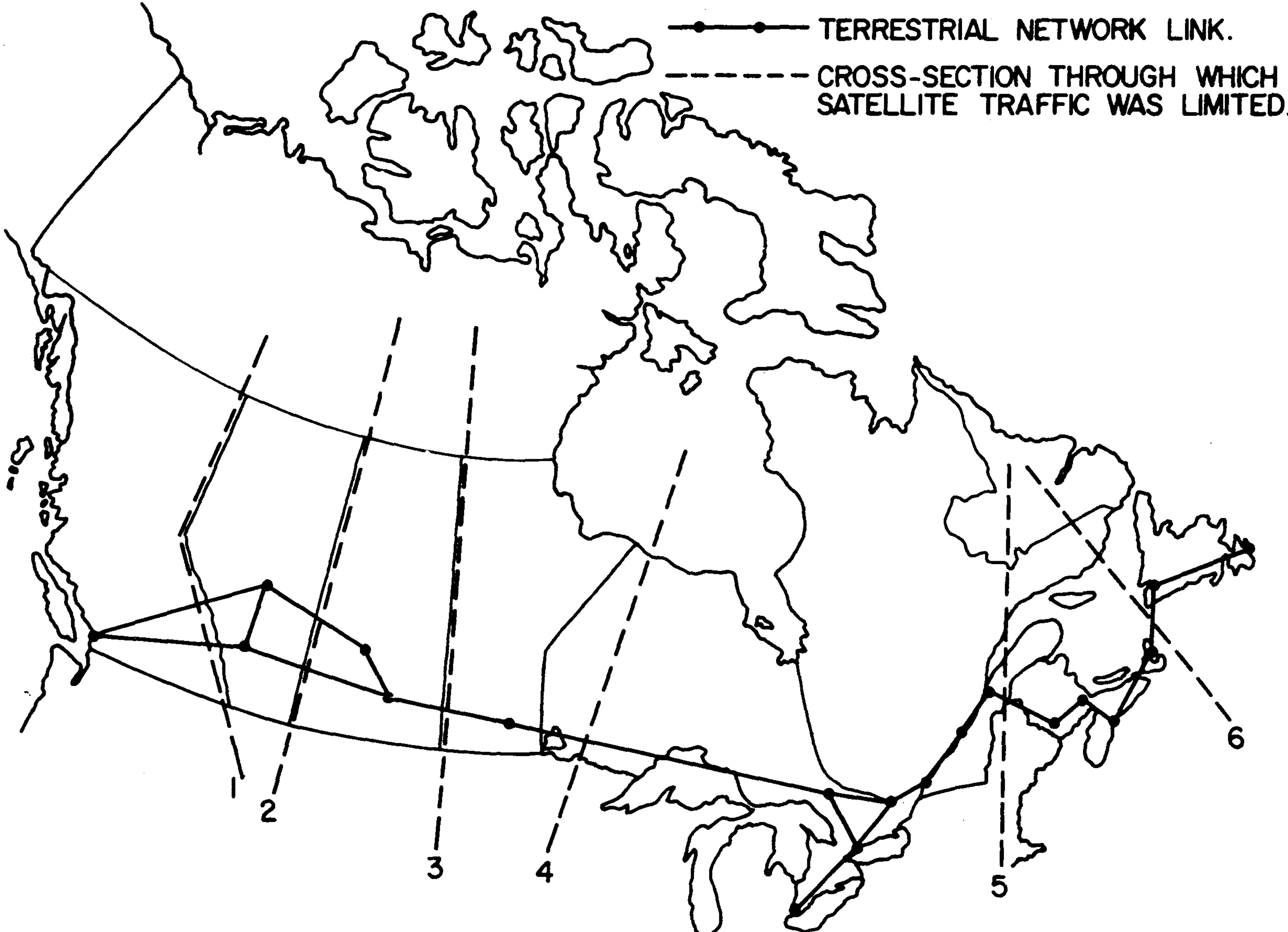

Figure 4.1: Trans-Canada Terrestrial Network and Cross-Sections of Limited Satellite Traffic

Table 4.3

Salient Features of

Three Attractive Satellite Systems

for the 1980-87 Period

Satellite Type	Number of Orbiting Satellites	Satellite Voice Traffic Limit	Satellite Weight, lb.	Number Antennas per Gnd. St.	Annual System Costs, Millions		
					Satellite System	Terrestrial Systems	Total
Anik	3	50%	650	2	26.73	40.95	67.7
RCA	2	33 1/3%	1060	1	24.43	42.89	67.3
RCA	2	50%	1095	1	25.55	40.95	66.5

year less than the network with Anik-like satellites. Note, however, that the latter includes dual antennas at all the major ground stations in southern Canada, at a cost of $1.2 million per year. The dual-Anik satellite system has the following advantages to compensate for its slightly greater cost.

i) The satellite system, and so the overall network, has greater protection against catastrophic failure. The satellite system on its own has immediate protection over 50% in the event of the failure of either an operational satellite or a ground-station antenna. The system with one operational RCA-type satellite has no such protection. (Both have 100% protection as soon as the in-orbit spare can be used.)

ii) The system is able to operate better during a solar transit, because only one of the two operating satellites is affected by the solar noise at one time. If antennas at the ground stations such as the COMSAT toroidal antenna were used, with a beam to each of the three in-orbit satellites, the solar transit problem could be completely avoided.

iii) Telesat has operational experience with the Anik-like satellite, and already Telesat is planning to launch a third Anik. As indicated, such a system will meet the expected domestic requirements until the mid-1980's without any problems of conversion to a new system.

For these reasons, a satellite system with three orbiting Anik-type satellites is preferred for the 1980 to 1987 time-frame.

The satellite system meets the expected northern requirements and carries all the southern nationwide television programs, as explained in Secion 4.1. In addition, it carries the voice circuits shown in Fig. 4.2, a total of about 9200 voice circuits. Dedicated transponders carrying voice circuits encoded with SPEC or a similar system are used for the heavier links. A combination of 4 phase PSK and 8 phase PSK is the anticipated transmission technique. It is expected that TDMA would be used to combine several of the smaller links on one transponder. 4 phase PSK with SPEC encoding could be used on the more lightly loaded links.

With the above television and voice traffic-handling capability of the satellite system in the early 1980's, the circuit requirements of the TCTS 4 GHz analog microwave radio system in the 1980's is shown in Fig. 4.3. This system carries

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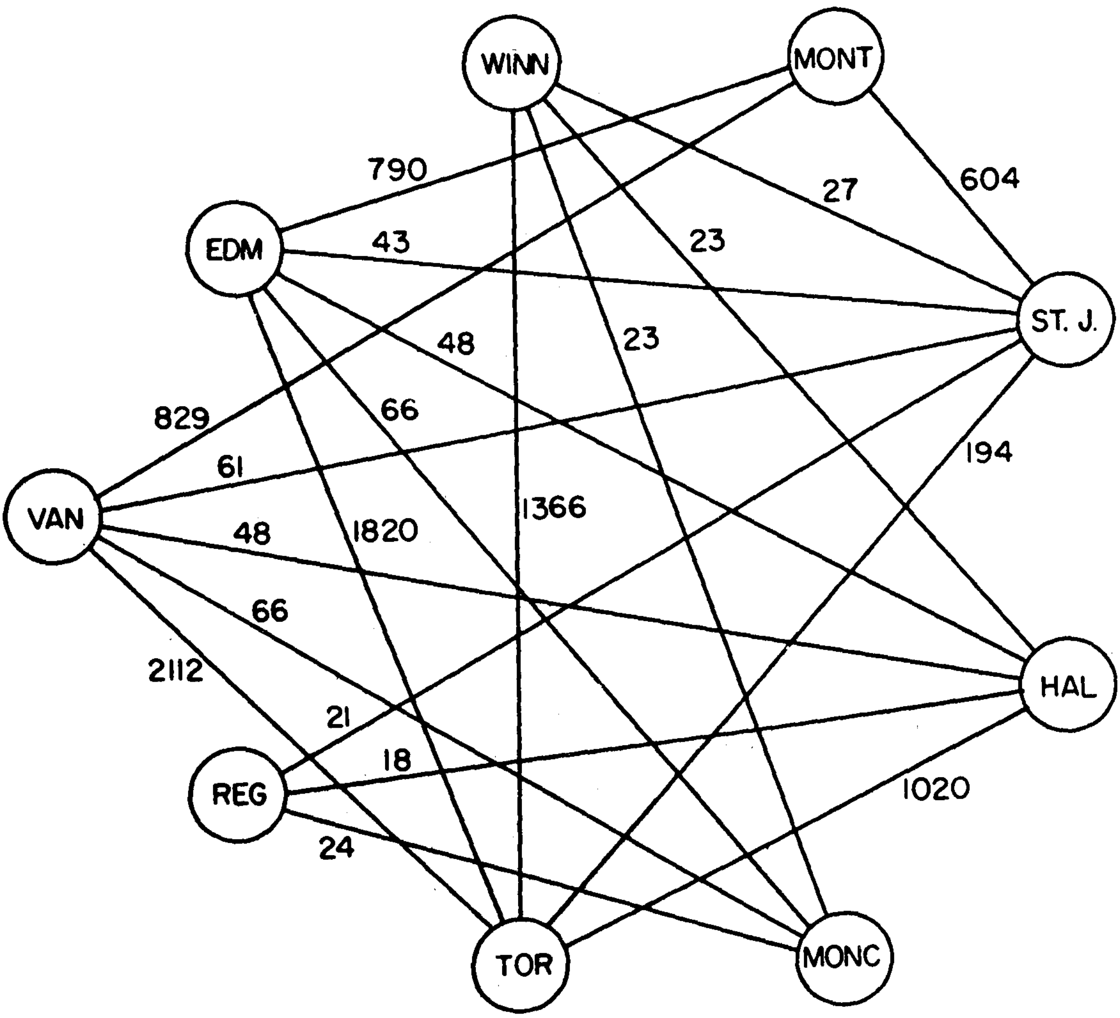

Figure 4.2

Voice Circuit Loading
Through Satellite System
in 1985

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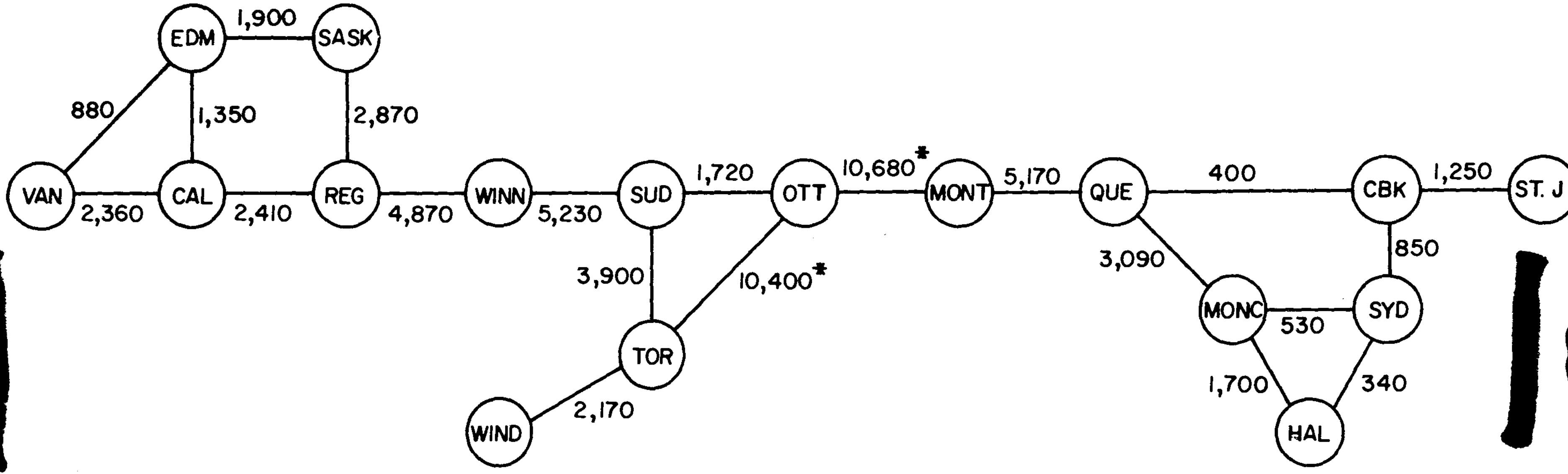


* PART OF THIS TRAFFIC WILL BE ON THE LD-4 CABLE SYSTEM.

Figure 4.3

Voice Circuit Loading
On TCTS Analog Radio Network
in the 1980's

the 1980 voice circuit requirements of TCTS, except for 1,000 voice circuits between Vancouver and Toronto. (The present Anik system has a 960 voice circuit capability between Allan Park and Lake Cowichan). It is assumed that this system is frozen at its 1980 level, not including the present requirements for television distribution. The requirements shown in Fig. 4.3 are approximately equal to the total TCTS requirements in 1973, including the distribution of two CBC and one CTV television program. Since CBc has since begun to distribute their first national programs by Anik satellite, this indicates that the TCTS 4 GHz analog system has already reached its maximum growth as a medium for long-haul transmission, although its potential capacity is several times that presently installed.

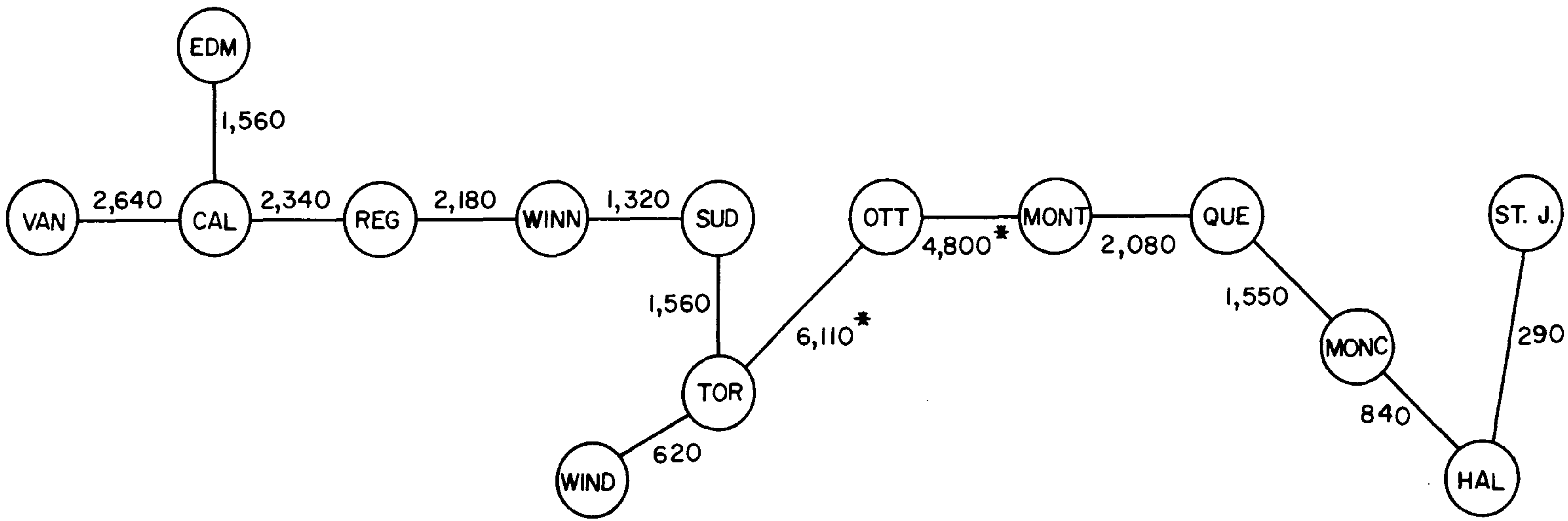
The growth of the TCTS terrestrial network after 1980 is expected to be all digital. The medium is expected to be the 8 GHz digital radio system, an add-on to the 4GHz analog radio system. In addition the LD-4 cable system between Toronto and Montreal will be part of the digital network. If the traffic requirements shown on Fig. 4.2 are carried by satellite, the expected circuit requirements of the TCTS digital network in 1985 are as shown in Fig. 4.4. Without use of SPEC, the capacity of an 8 GHz radio channel is 672 voice circuits, so it is likely most links in the system will have several equipped radio channels by 1985.

Recently acquired voice-traffic information indicates that the requirements between Toronto and Montreal may be significantly greater than that shown in Fig. 4.4. However, this change has no effect on the trade-off between satellite and terrestrial systems, since the Toronto-Montreal link is quite short in comparison with other network distances.

Based on the assumptions that CNCP will continue to carry about 16% of the long-haul voice and data traffic, and that the satellite voice traffic would be as shown in Fig. 4.2, the expected voice circuit requirements of the CNCP network in 1985 are as shown in Fig. 4.5. These requirements could easily be met by increasing the number of radio channels on the present 6 GHz analog radio system.

4.4.2 MINIMUM-COST NETWORK FOR THE 1987-1994 INTERVAL

When choosing a satellite system for the 1980-1987 time interval, and thereby determining to a large extent the growth of the terrestrial systems in that time interval, it is necessary to consider growth of the network beyond that interval. This is because any terrestrial system or satellite ground station that is installed in the 1970's or early 1980's will be usable at a



* PART OF THIS TRAFFIC WILL BE ON THE LD-4 CABLE SYSTEM.

Figure 4.4

Voice Circuit Loading
On TCTS Digital Radio Network
In 1985

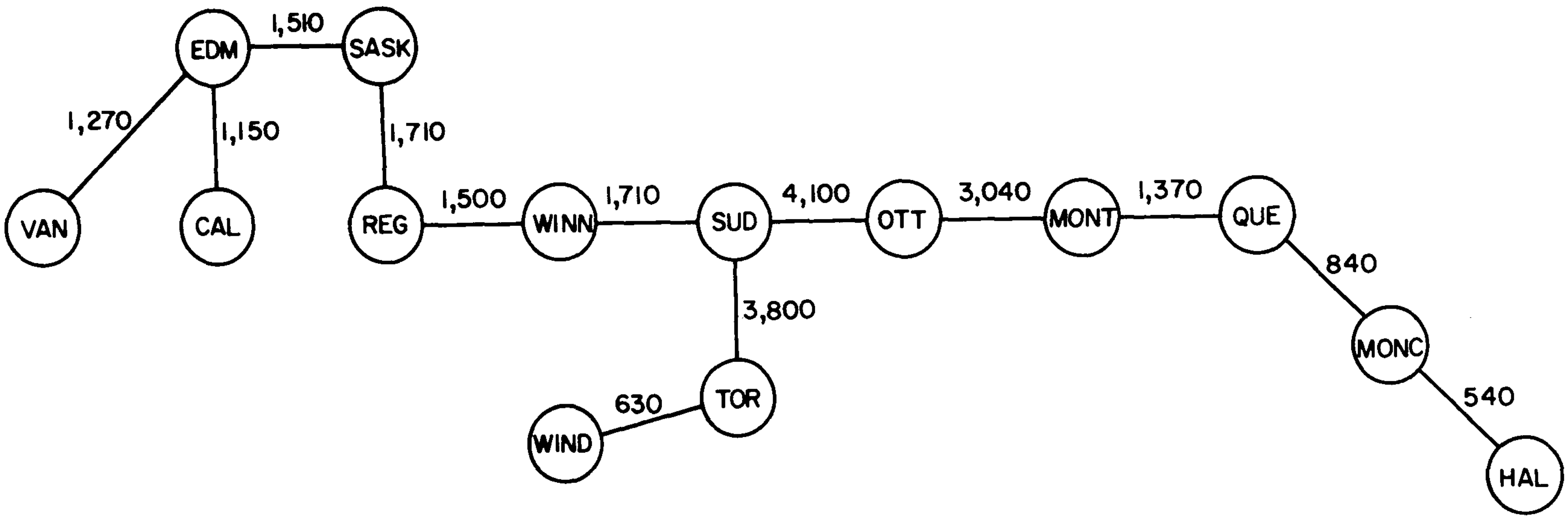


Figure 4.5

Voice Circuit Loading
On CNCP 6 GHz Analog Radio Network
In 1985

later date. It is shown below that the nearly-minimum-cost network with two operational Anik satellites in the early 1980's is fully compatible with the network which carries the preferred traffic estimate at minimum cost. Thus there is no compatibility problem in network evolution throughout the 1980's.

Several different satellite scenarios were considered for use in the 1987-1994 time-frame. Included were:

i) One large satellite at 4/6 GHz for all services, with an in-orbit back-up;

ii) two identical satellites at 4/6 GHz, plus one in-orbit back-up, for all services;

iii) satellites similar to those in i) and ii) except for the use of 12/14 GHz for voice traffic only in Southern Canada, for all services in Southern Canada, or for all services in both north and south;

iv) satellite systems similar to those in iii) except for the use of 4/6 GHz and 12/14 GHz on separate satellites.

The most cost-effective satellite system is that with two identical operational satellites at 4/6 GHz, plus one in-orbit back-up. This system is described below. The other possible satellite systems are discussed and compared in sections 4.6 and 4.7.

The most cost-effective network in 1990 includes two operational satellites similar to the RCA-Globcom satellite, plus an in-orbit backup. This satellite system would meet the northern thin-route voice and television requirements, would be used to distribute all nationwide television programs in southern Canada, and would carry up to 50% of the long-haul voice traffic in southern Canada. The amount of voice traffic in southern Canada that is carried on the satellite is limited primarily by network survivability requirements rather than the comparative costs of transmission through satellite on terrestrial media.

The voice circuit loading of the satellite system in 1990 is shown in Fig. 4.6. The satellite system carries 50% of the total number of voice circuits through several of the cross-sections shown in Fig. 4.1. In 1990 ten satellite transponders are required for northern services and twenty four for southern services, a total of thirty four, if SPEC and DITEC

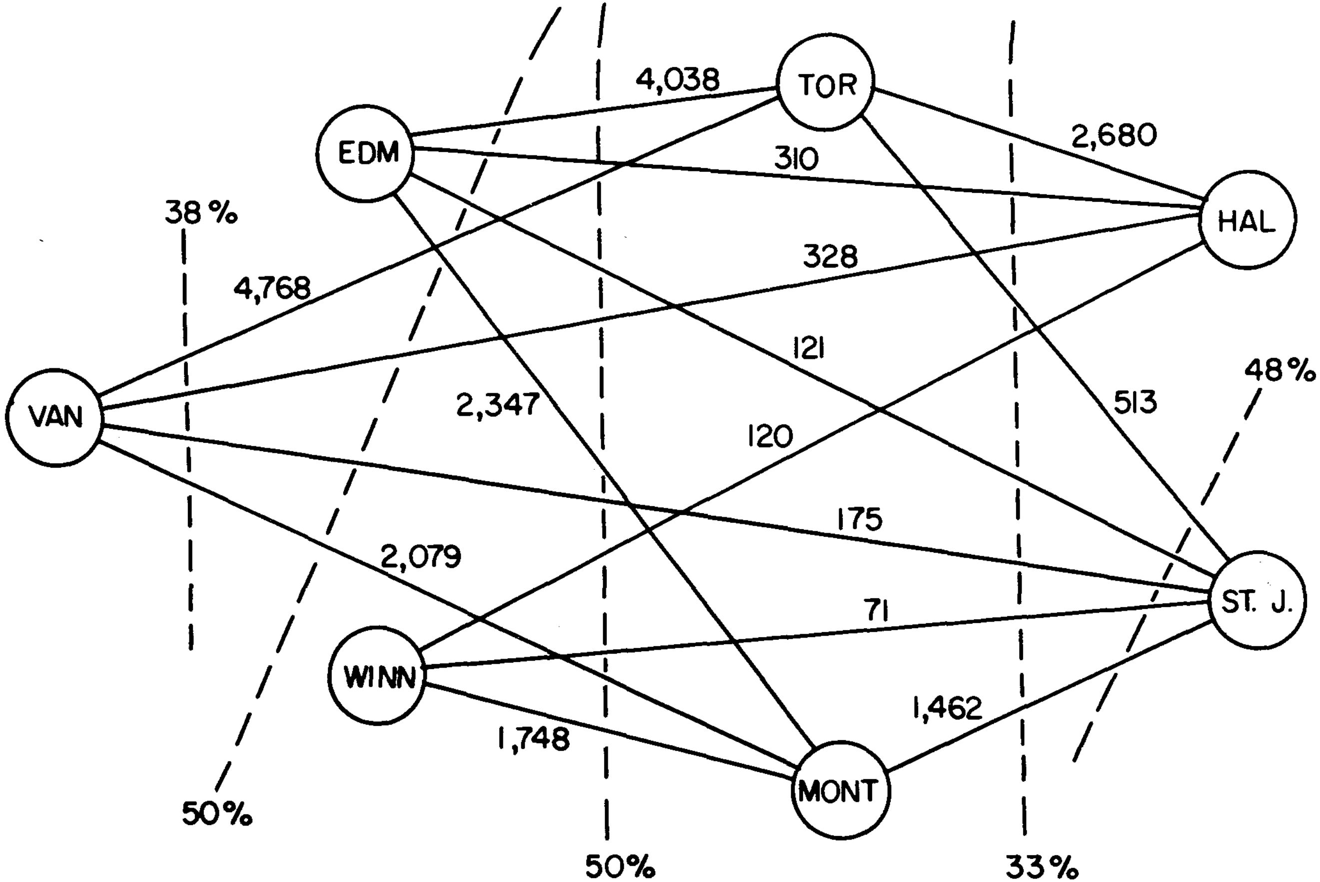


Figure 4.6

Voice Circuit Loading
Through Satellite System
In 1990

are used extensively. It is expected that between 40 and 44 of a total of 48 transponders will be available at the end of the satellite system's nominal lifetime, 1994, so there is ample capacity for system expansion from 1990 to 1994.

In the 1987-1994 time frame there are several important differences in the way the satellite system is used for voice traffic from its use in the earlier 1980-87 time frame. These include:

i) In the later time-frame a much higher percentage of satellite voice circuits are through dedicated transponders, rather than through transponders shared by a TDMA technique. In 1990 the satellite system carries 20,800 voice circuits, compared with 9,200 in 1985. However, the number of TDMA voice voice circuits in 1990 is only 1,640, less than the 2,300 voice circuits in 1985.

ii) In 1990 there are fewer ground stations handling voice traffic than in 1985. (See Fig's 4.2 and 4.6). This is because by 1990 the network survivability constraint is the dominant factor in determining the satellite voice traffic, and because the satellite traffic is dominated by traffic between Vancouver and Edmonton in the west to Toronto and Montreal in the east.

Three other possible satellite systems are considered below, primarily to indicate the effect of routing large quantities of voice traffic through the satellite system. These systems all operate at 4/6 GHz, and use either Anik-type satellites or RCA-type satellites. The salient features of the most cost-effective system and three possible alternatives are summarized in Tables 4.4 and 4.5. Other possible satellite systems which use the 12/14 GHz band, either exclusively or in addition to the 4/6 GHz band, are discussed in later sections.

One possible alternative shown in Table 4.4 is to route all voice and data traffic in southern Canada through the terrestrial network, and to provide northern services and route nationwide television programs in southern Canada through the satellite system. As explained in section 4.2.2, the most cost-effective satellite system to meet this demand is a single RCA-Globcom-type satellite plus in-orbit backup. Fourteen to sixteen satellite transponders would be required in 1990 if DITEC were used for television distribution. Thus there would be 4 to 8 transponders available for expansion of services in the 1990 to 1994 interval.

Table 4.4

Annual Cost Comparison of Networks

to Handle 1990 Expected Requirements

Satellite Type	Number of Orbiting Satellites	Satellite Voice Traffic Limit	Satellite Weight, lb.	1990 Annual Network Costs, Millions of 1973 Dollars		
				Satellite System	Terrestrial Systems	Total
RCA	3	50%	960	34.6	62.9	97.5
Augmented RCA	2	33 1/3%	1105	30.4	69.1	99.5
Augmented Anik	3	50%	680	31.8	69.1	100.9
RCA	2	0	1050	25.4	77.2	102.6

Table 4.5

Comparative Evaluation of 4/6 GHz Satellite Systems

for the 1987-1994 Time-Frame

Satellite System	Network Annual Cost in 1990, Millions of 1973 Dollars	Compatibility with Network of Early 1980's	Operation During Solar Transit	Protection Against Catastrophic Failure	Capacity For Expansion in 1990-94
Dual RCA Type	97.5	Good	Fair*	Good	Good
Single Aug-Mented RCA Type	99.5	Poor	Poor	Fair	Poor
Dual Aug-mented Aniks	100.9	Good	Fair*	Good	Poor
Single RCA Type	102.6	Poor	Poor	Fair	Good

*This rating would be "good" rather than "fair" if a toroidal antenna rather than dual parabolic antennas were used.

[redacted]

A second possible alternate system is to use an augmented RCA-type satellite, plus in-orbit backup, so that considerable voice traffic could be routed through the satellite system in addition to the television and northern traffic. By "augmented" we mean the addition of several redundant transmitters and other equipment so that the full 24 transponders can be used on the satellite near the end of its nominal lifetime during solar eclipse. (Note that the Intelsat IV satellite is designed in this way, but the present Anik satellite is not.) If such a system were used 10,300 voice circuits could be carried on the satellite system. This is about half the amount of voice circuit traffic that is carried cost-effective on the larger satellite system in 1990. Moreover, there is no possibility for growth of the satellite system in the 1990-1994 interval.

The third possibility of Table 4.4 is to use two augmented Anik-type satellites to carry the same traffic as that carried by single RCA-type satellite. If we assume that a dual-Anik satellite system is used in the earlier 1980-87 time frame, the recommended satellite system for that interval, then a continuation of the dual-Anik system into the 1987-94 time frame results in less new costs than the augmented RCA-type satellite system. However, use of this dual-Anik-type system results in considerably higher network cost than use of the larger dual-RCA-type satellite system, while at the same time resulting in poorer overall network protection against catastrophic system failure. Thus the use of two RCA-type satellites, plus in-orbit backup, seems the best choice for the 1987-94 time-frame. It will be shown in sections 4.7 and 4.9 that this system is more cost-effective than any use of the 12/14 GHz band.

As shown in Table 4.4, the largest of the four satellite systems, the dual RCA satellite system, is part of the least costly network. Several other important characteristics of the four possible systems are summarized in Table 4.5. As shown, the dual RCA-type system, and its associated network, has the best rating in all the important areas.

With the satellite system carrying all the nationwide television programs, and the voice circuits shown in Fig. 4.6, the expected circuit requirement for the TCTS digital network in 1990 is as shown in Fig. 4.7. It is expected that the transmission media in this network will be 8 GHz digital radio into the 1990's, apart from the LD-4 coaxial cable system between Toronto and Montreal, or perhaps between London and Quebec City. Note that the loading shown in Fig. 4.7 was determined on the assumption that the TCTS analog radio system would continue to be loaded at its 1980 level, shown in Fig. 4.3. In contrast, if the TCTS terrestrial long-haul network were completely digital by 1990 the loading would be significantly greater than that shown

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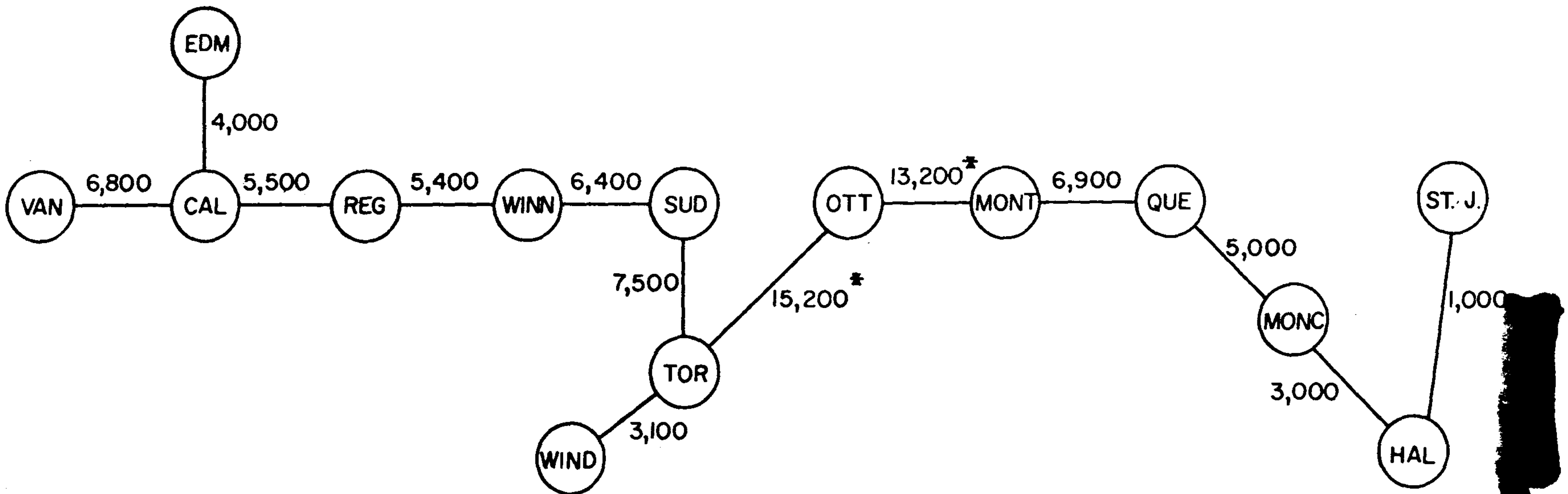


*PART OF THIS TRAFFIC WILL BE ON THE LD-4 DIGITAL CABLE SYSTEM

Figure 4.7

Expected Voice Circuit Loading
On TCTS Digital Radio Network
In 1990

in Fig. 4.7. The most heavily loaded links outside the Windsor-Quebec City corridor would be the Toronto-Sudbury link and the Sudbury-Winnipeg link, each with about 12,000 voice circuits. However, this is considerably less than the full-load capacity of the 8 GHz system. Two parallel 8 GHz radio systems could be loaded to 27,000 voice circuits, or to about 50,000 voice circuits if an encoding scheme such as SPEC were used. Thus the 8 GHz digital radio system will not saturate until well into the 1990's.

The loading on the CNCP 6 GHz analog radio terrestrial network in 1990 is shown in Fig. 4.8. The ultimate capacity of the 6 GHz radio system is 10,800 voice circuits. As shown, no link in Fig. 4.8 is close to saturation, except perhaps the Toronto-Montreal link through Sudbury and Ottawa. CN/CP may construct a direct Toronto-Montreal link in the late 1980's, but no other expansion will likely be required until the 1990's, even if the satellite system is not used extensively for voice and data transmission.

If the satellite system were used to meet northern requirements and distribute nationwide television programs in southern Canada, but not to carry voice or data traffic between southern cities, the loading on the terrestrial networks would be as shown in Fig's 4.9 and 4.10. As indicated, no link loading in either the TCTS or the CNCP network is close to the ultimate capacity of the link. Thus no entirely new terrestrial link will be required in Canada until the 1990's, except perhaps a CNCP link from Toronto to Montreal.

In summary, a large number of possible networks for the 1980's have been compared by evaluating their annual costs in 1985 and in 1990. It has been shown that a dual Anik satellite system in the 1980-87 interval, followed by a dual RCA-Globcom-type satellite system in the 1987-94 interval, is the most cost-effective system. In the following section this will be verified by comparing the present value of network costs of this system and an alternate one in which only northern services and southern nationwide television are carried on the satellite.

4.4.3 COMPARISON OF THE PRESENT VALUE OF THE COST OF THE POSSIBLE NETWORK EVOLUTIONS

In the previous sections, several possible satellite - terrestrial network evolutions throughout the 1980's were compared by evaluating their annual costs in 1985 and 1990. This technique was used because it was considerably easier to do than a present value calculation and because it could be built into a

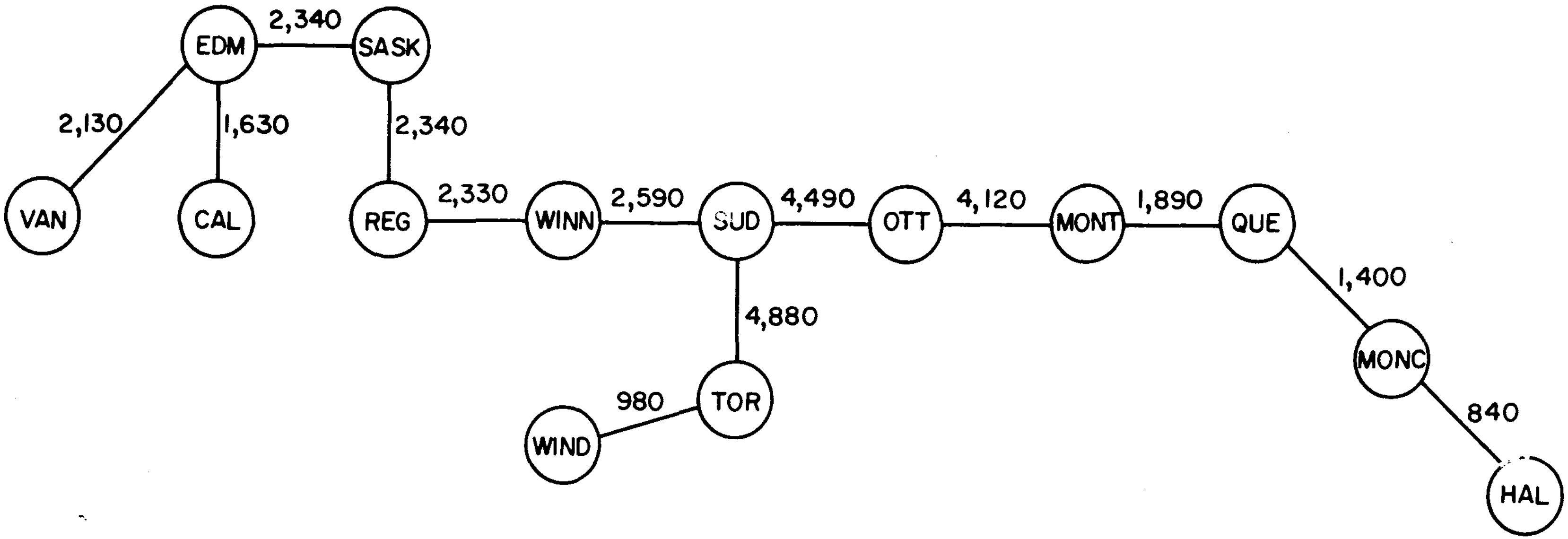


Figure 4.8

Voice Circuit Loading
On CNCP 6 GHz Analog Radio Network
In 1990

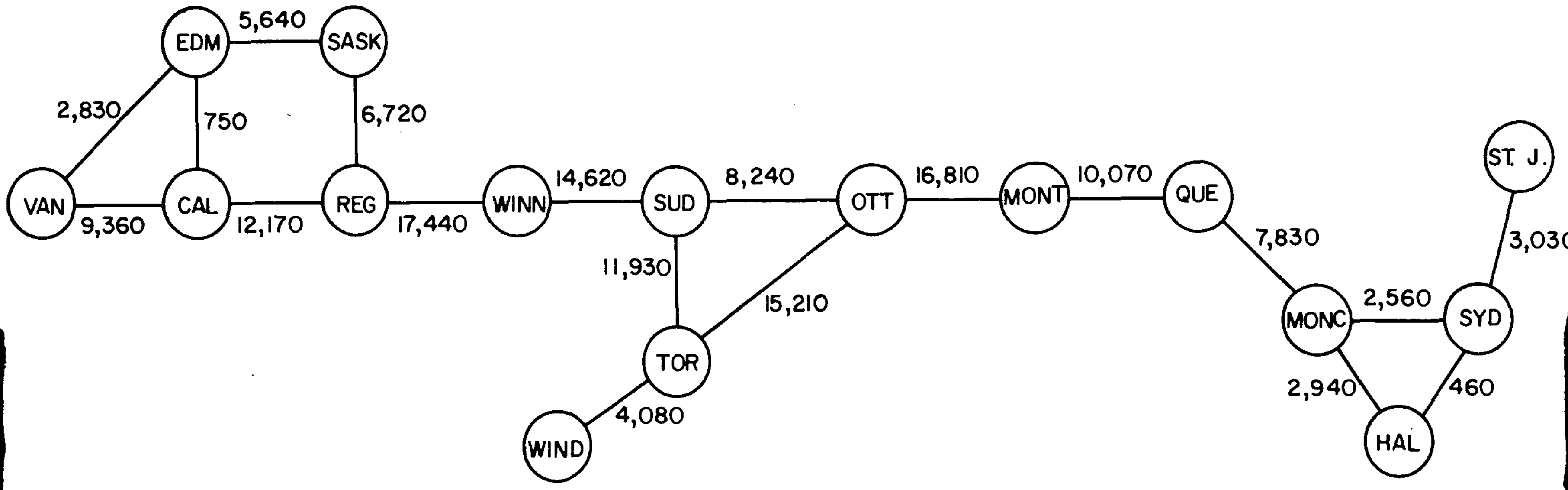
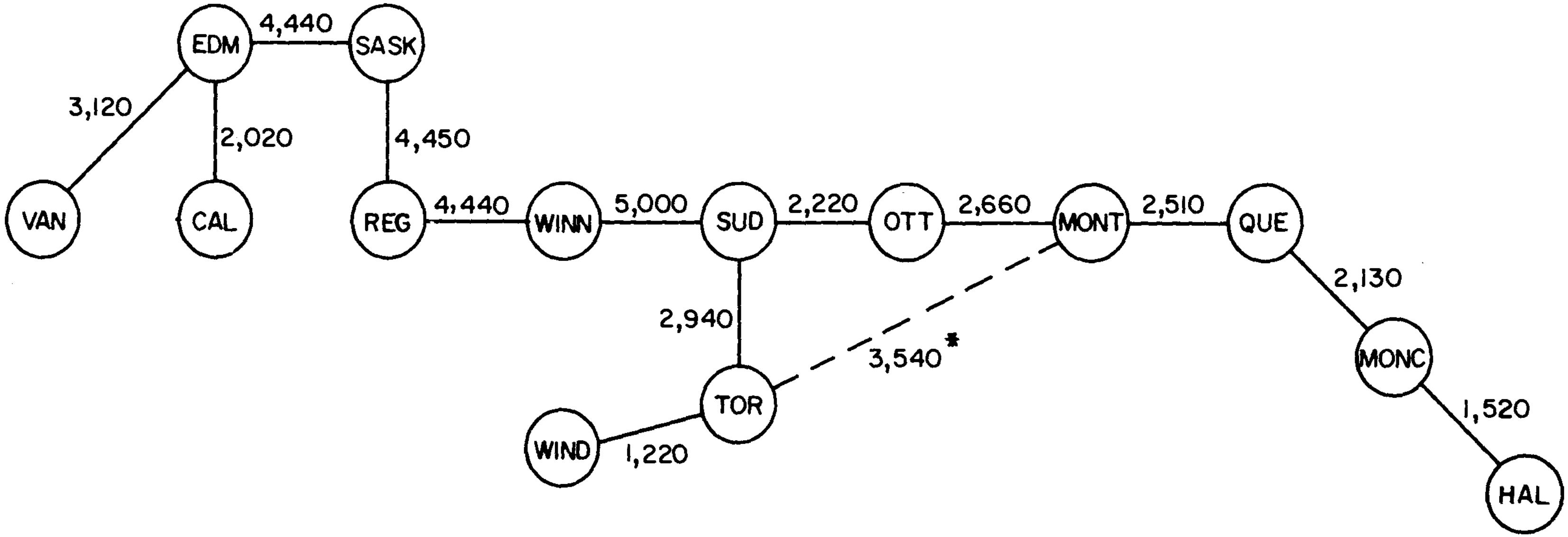


Figure 4.9

Preferred Forecast of
Voice Circuit Loading on TCTS Digital Network in 1990
With No Voice Traffic Through Satellite



*A POSSIBLE NEW LINK.

Figure 4.10

Preferred Forecast of
Voice Circuit Loading on CNCP 6 GHz Analog Network in 1990
With No Voice Traffic Through Satellite

[redacted]

network synthesis algorithm. However, the possibility that a more extensive present-value calculation would indicate a more cost-effective network expansion had to be considered. For this reason, the present value of the costs of two significantly different attractive network possibilities are determined in this section.

The following results of the previous sections can be used to choose which systems should be compared:

i) Northern services and southern nationwide television programs should be carried by satellite. (This result is very conclusive, and would hold up under almost any economic comparison of systems.)

ii) If only the above services are carried on the satellite, an augmented Anik satellite would meet the requirement in 1980-87, and an RCA-type satellite as a follow-on in the 1987-94 interval.

iii) If a large amount of southern voice and data traffic is to be carried on the satellite, two Anik satellites are required to carry traffic in 1980-87, and two RCA-type satellites in the later 1987-94 interval.

The present value of the costs of the networks with the satellite systems described in (ii) and (iii) above are compared below. Let us first specify how this cost comparison is made. As in the annual cost calculations, the only costs which are considered are the capital cost of new equipment, the installation of that equipment, and the maintenance and operation of all equipment in the network. Other "costs", such as return on equity, corporation tax, municipal tax of property, etc. are not considered as costs in any part of the study. Suppose that $Cj(k)$ is the capital spent on network j in the year k, and that $Mj(k)$ is the maintenance and operation cost incurred in keeping network j in operation during year k. If costs from year Y_1 to year Y_2 are to be included in the cost comparison, and if i is the annual cost of money in the interval Y_1 to Y_2, then the present value of the cost of network j in the year Y_1 is:

$$P(j) = \sum_{k=Y_1}^{Y_2} \left\{ Cj(k) + Mj(k) \right\} \left\{ 1 + i \right\}^{-(k-Y_1)} \quad (4.1)$$

[redacted]

 [redacted]

Rather than determine $P(j)$ for each system, the difference

$$\Delta P = P(1) - P(2) \tag{4.2}$$

was determined, with $Y_1 = 1980$ and $Y_2 = 1994$, the end of the interval of interest. This allowed us to ignore any costs common to the two networks being compared. Further information on the comparison of cash flow in the two network options was obtained by evaluating the difference:

$$\begin{aligned}\Delta P(n) &= P(1,n) - P(2,n) \\ &= \sum_{k=Y_1}^{Y_1+n} \left\{ C_1(k) + M_1(k) \right\} \left(1+i\right)^{-(k-Y_1)} \\ &- \sum_{k=Y_1}^{Y_1+n} \left\{ C_2(k) + M_2(k) \right\} \left(1+i\right)^{-(k-Y_1)}\end{aligned} \tag{4.3}$$

as a function of n. $\Delta P(n)$ is the difference in the present value of the money spent on network 1 and network 2 from the year Y_1 to and including the year $Y_1 + n$.

Let us now examine $\Delta P(n)$ of the two networks of interest. The network with the satellite system to meet northern and southern nationwide television requirements is arbitrarily denoted as network 1, and the network with the larger satellite system to carry up to 50% of the long-haul voice traffic as network 2. Y_1 is set at 1980, the beginning of the period of interest. $\Delta P(n)$ is shown in Fig. 4.11 over the range n = 0 to n = 14 for interest rates i = 8%, 10%, and 12% in (4.3).

Several observations can be made of the data presented on Fig. 4.11. These include:

[redacted]

[redacted]

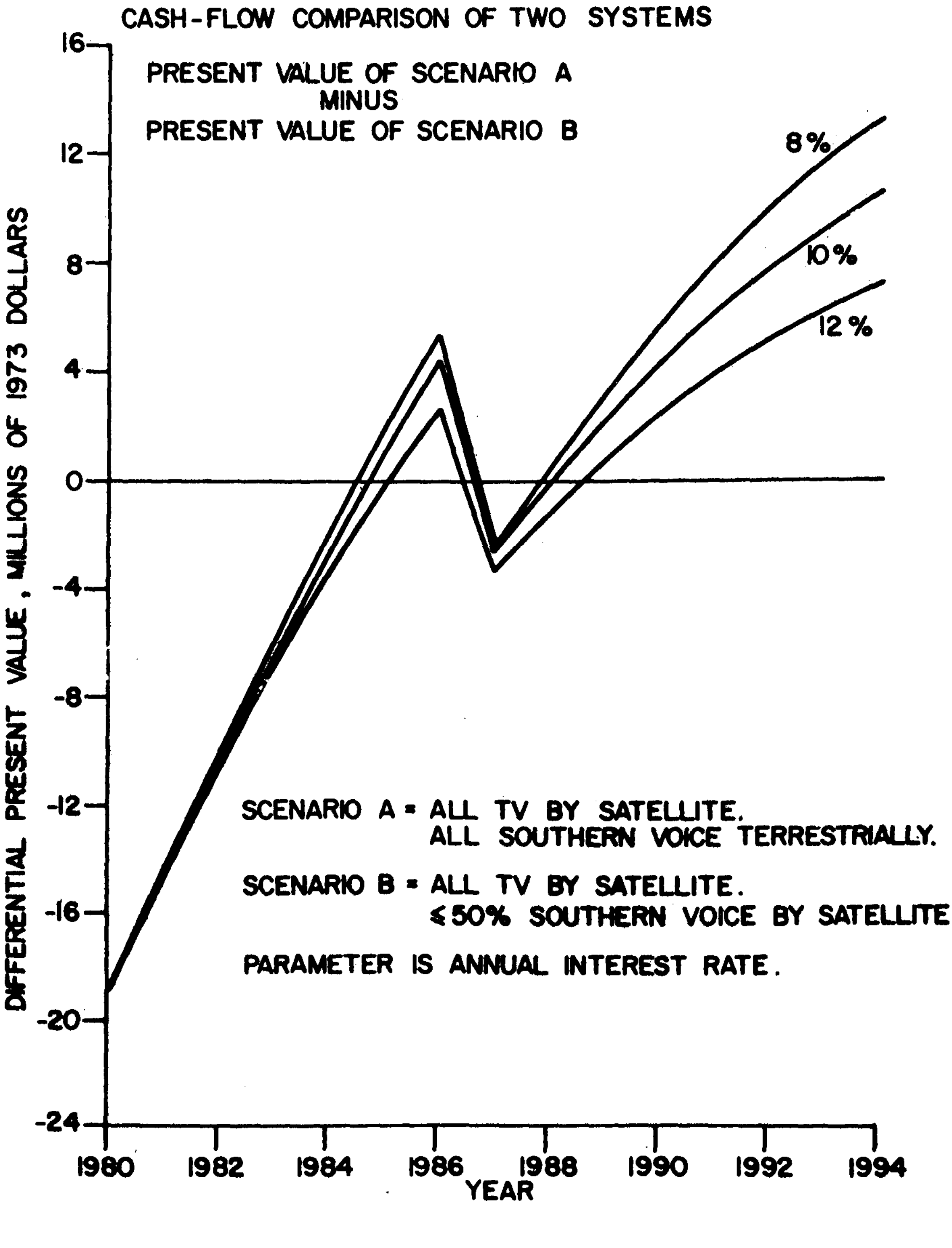


Figure 4.11

[redacted]

i) Over the 14 year period, the lifetime of two satellite systems, the present value of the saving made by using the larger dual satellite systems is considerable: between $6 million and $14 million dollars, depending on the cost of money during the 14 year period.

ii) Over the shorter 7 year period of one satellite system there is still a saving to be made by using the larger satellite system. In this case the saving is between $2 million and $5 million, again depending on the cost of money during the 1980-87 interval.

iii) The extra initial cost of the larger satellite system is quite large, 19.2 million 1973 dollars in 1980 and 19.5 million 1973 dollars in 1987. This accounts for the large initial negative value of P(n) in Fig. 4.11, and the large negative step in 1987. However, as shown, the savings gained by requiring a much less costly terrestrial network more than counter-balances this initial expenditure.

Thus the more precise present value calculations verify the result obtained by using annual costs to compare the various possible network evolutions. Both analyses indicate that the use of a dual Anik satellite system in 1980-87 and a dual RCA-type satellite system in 1987-94 is the least expensive system. Moreover, this network evolution is quite compatible with the present system, and allows for smooth and flexible growth throughout the 1980's.

4.5 THE ADDITION OF CBC REGIONAL TELEVISION DISTRIBUTION TO THE REQUIREMENTS OF THE SATELLITE SYSTEM

The prime objective of the DLDCNS was to determine the most cost-effective satellite/terrestrial transmission network in the 1980's to meet the northern communications requirements, to distribute nationwide television programs, and to carry long-haul voice traffic in southern Canada. As the study progressed it became obvious that the satellite system would be a significant part of the network in the 1980's, and that the satellite would carry almost all the nationwide and northern regional television programs. With this background, the question of whether CBC regional television distribution should be distributed in southern Canada with the satellite system became quite relevant.

A study of whether the regional television should be distributed in a given province terrestrially or through the satellite could not be easily carried out, because the model of the terrestrial network used in the study was not detailed enough to make comparisons at the regional level. (The network model is described in Appendix B). In fact, the details of the terrestrial network within a province were intentionally omitted to simplify the model. Because of this, and because of time and manpower limitations, it was decided to answer a simpler question regarding regional television distribution: What would be the best way to add a regional-television-distribution capability to the satellite system, and what would be the cost of that addition?

The first thing that must be determined in answering this question, as in doing the overall DLDCNS study, is an estimate of the number of programs that might be distributed through the satellite. An upper bound on this estimate is sixteen: English and French signals in each of the eight CBC regions. However, some programs go to very few stations within a given region; it is very unlikely that such distribution would be by satellite. In a BNR satellite system feasibility study for DOC and CBC it was estimated that there will be eight regional TV programs distributed to 10 or more stations in the 1980-85 time-frame. These programs are:

English in British Columbia with 14 stations,
English in Saskatchewan with 11 stations,
English in Manitoba with 19 stations,
English in Ontario with 27 stations,
French in Ontario with 10 stations,
French in Quebec with 29 stations,
English in the Maritimes with 11 stations,
English in Newfoundland with 12 stations.

Taking the above eight programs as the potential requirement for regional TV distribution in southern Canada in the 1980's, the question that is answered below is how to meet this requirement with a minimum-cost satellite system.

There are several technological "options" available in designing a regional-television distribution system by satellite. The choices include:

i) Choice of carrier frequency, either 4 and 6 GHz or 12 and 14 GHz.

ii) Choice of modulation technique, either analog FM or digitally with DITEC encoding.

iii) Trade-off of system (EIRP + G/T) by choosing the satellite antenna pattern, satellite transponder power, receiver antenna size, and receiver voice figure.

Let us first consider carrier frequency and modulation technique. Flux density limitations in the 4/6 GHz band require that large ground station antennas be used if analog FM is used. (The problem is the danger of "spikes" in the spectrum of the received television signal.) In contrast, if digital transmission with DITEC and an efficient modulation scheme such as 4 phase PSK is used, quite small receiving antennas may be used. It is shown in Appendix G that quite small antennas may be used for digital transmission at 4/6 GHz. Moreover, the BNR study has shown that the use of digital transmission with DITEC and 4 phase PSK is more economical than analog FM at 12/14 GHz. Thus it can be concluded that any satellite system would use digital transmission, DITEC, and 4 phase PSK, either at 12/14 GHz or at 4/6 GHz. It was assumed that any satellite regional-television distribution system would be at 4/6 GHz in 1980-87, but that either could be used if distribution by satellite was not introduced until 1987.

The next area in which the number of technological options can be reduced easily is the choice of antenna systems for the spacecraft and the receiving ground stations. Use of regional antenna beams on the spacecraft, about 2.4° by 1.2°, are cost effective both to reduce the necessary transponder power and weight, and to allow frequency re-use. On the ground-station side, small antennas should be used to reduce overall system cost, since these will likely be about 133 ground stations if the satellite system is cost-effective. Based on this information it was assumed that 16' fixed antennas would be used at the ground stations.

With the above assumptions, description of the satellite system from an exogenous viewpoint is reduced to a trade-off between satellite transponder power and receiver noise temperature. Again, since there will be well over a hundred ground stations, the ground station costs must be minimized. Comparisons were made at both 4/6 GHz and at 12/14 GHz between systems with 24 dB and 29 dB noise temperatures. At 4/6 GHz these would use transistor or uncooled paramp. preamplifiers respectively, and at 12/14 GHz would use tunnel diode or uncooled paramp. preamplifiers. The characteristics and costs of these ground stations are summarized in Table 4.6. Also shown are the satellite transponder powers required for each type of ground station.

Table 4.6

Salient Characteristics of

Possible Satellite Regional TV Distribution Systems

Satellite Antenna Beams:	$2.4^{\circ} \times 1.2^{\circ}$
Antenna Diameter at Receiving Site	16'
System Modulation Technique	4 phase PSK with DITEC
Transponder Bandwidth	20 MHz

Satellite Downlink Frequency	Receiver Preamp Type	Receiver System Noise Temperature	Satellite Transponder Power, Watts	Receiving Site Capital Costs, X $,000 1973 Dollars
4 GHz	Transistor	29 dB$^{\circ}$K	7.3	80
4 GHz	Paramp	24 dB$^{\circ}$K	2.3	103
12 GHz	Tunnel diode	29 dB$^{\circ}$K	20.6	82
12 GHz	paramp	24 dB$^{\circ}$K	6.5	103

4.5.1 THE ADDITION OF A REGIONAL TV DISTRIBUTION SYSTEM IN 1980-87

As stated above, it was assumed that if a regional TV distribution system were installed for operational use in the 1980-87 time-frame, it would use the 4/6 GHz band. (The 12/14 GHz band could be used, especially if use of the 4/6 GHz band for this purpose proved to be infeasible. However, such is not the case, as is shown below and in the results shown in Table 4.6. A comparison of the use of the 4/6 GHz band and the 12/14 GHz band will be made below when considering the 1987-94 time-frame). In this section the possibility of adding a 4/6 GHz regional TV distribution system to the dual Anik system that was recommended in the previous section is investigated. As well, the addition of a regional TV system to the single Anik system, the system without any southern voice circuits on the satellite, is investigated.

The weight and cost of the satellites with the regional TV distribution subsystem added was estimated with the technique that is described in Appendix C. Note that in the dual Anik system each satellite need carry only 4 of the 8 regional TV programs, since the different regions can use either of the two satellites. In contrast, in the network in which there is only one operational satellite, plus an in-orbit spare, that satellite must carry all 8 regional TV programs. Thus the weight addition to the single satellite will be considerably greater.

The costs and weights of the satellite subsystems to carry the regional TV programs are given in Table 4.7. Note that the satellite weights, and so the cost of the space portion of the satellite syste, are considerably smaller when the lower noise ground stations are used. Each of the four systems described in Table 4.7 would likely have a satellite bus similar to the RCA-Globcom satellite.

The total system costs are given in Table 4.8. There are three main conclusions that can be reached from this table and Table 4.7. They are:

i) The overall system cost is $8.5 to 9.0 million for all the systems considered, or about $1.1 million per television program. It is this cost that must be compared with the cost of distributing the eight programs terrestrially. (Note that this figure is a <u>cost</u>, not a <u>rate</u>. The terrestrial costs would be similar to those given in Appendix B.)

Table 4.7

Estimated Weights and Costs of

Satellites with Regional TV Distribution Subsystems Added

Satellite System Without Regional TV	Ground Station System Noise Temperature	Satellite Weight in Synchronous Orbit		Space Portion Annual Costs, Millions of 1973 Dollars		
		Without Regional TV	With Regional TV	Without Regional TV	With Regional TV	Regional TV Addition
Single Anik	24 dB^oK	536	1075	10.7	15.0	4.3
Single Anik	29 dB^oK	536	1167	10.7	15.5	4.8
Dual Anik	24 dB^oK	594	1020	14.5	18.9	4.4
Dual Anik	29 dB^oK	594	1073	14.5	19.3	4.8

Table 4.8

Estimated Marginal Annual Costs of

Satellite Regional TV Distribution System

for 1980-87 Time Frame

Satellite System Without Regional TV	Ground Station System Noise Temperature	Annual System Costs, Millions of 1973 Dollars			
		Space Portion	Ground Transmission System	Ground Receiving Sites	Total
Single Anik	24 dB$^{\circ}$K	4.3	1.0	3.6	8.9
Single Anik	29 dB$^{\circ}$K	4.8	1.0	2.8	8.6
Dual Anik	24 dB$^{\circ}$K	4.4	1.0	3.6	9.0
Dual Anik	29 dB$^{\circ}$K	4.8	1.0	2.8	8.6

[redacted]

ii) With about 130 receiving ground stations in the system it is slightly less expensive to use less costly ground stations and a more powerful satellite. The advantage gained by doing this would obviously increase as more ground stations were introduced.

iii) The maximum satellite weight for available launch vehicles may dictate what type of ground stations are used, since the cost advantage of using the larger satellite is quite small.

No major technical innovations are required to implement these systems: they require 2.4° by 1.2° satellite beams at 4 GHz, 7 or 8 watt satellite transponders, transistorized or uncooled paramp. preamplifiers at 4 GHz, and a television encoding scheme such as the DITEC system of COMSAT. Whether or not such a system should be used is dependent on whether it is less costly than an equivalent terrestrial system.

4.5.2 THE ADDITION OF A REGIONAL TV DISTRIBUTION SYSTEM IN 1987-94

As shown in 4.4.2 and 4.4.3, the most cost-effective network in 1987-94 includes a satellite system with three RCA-type satellites, including an in-orbit spare. The salient features of a satellite subsystem for regional television distribution would likely be still described by Table 4.6. The only other significant option that will likely be available in 1987-94, and not in 1980-87, is the use of the 12/14 GHz band. The addition of a regional-television-distribution subsystem to the RCA-type satellites is investigated here to determine:

i) what cost reduction can be expected by being part of the larger system;

ii) whether the use of the 12/14 GHz band would reduce the system costs;

iii) whether or not more sensitive higher cost receivers should be used.

It should be noted that ample spectrum space is available at 4 GHz, since only 34 of a maximum 48 transponders are required in 1990, not including that used for regional television distribution.

Estimates of the satellite weights and system costs with the various systems for regional television distribution added to

[redacted]

the satellite are given in Table 4.9. There are three main observations to be made from these results. They are:

i) The total subsystem cost is smaller when the less expensive ground stations and larger satellites are used, whatever subsystem carrier frequency is used. This advantage would of course increase as more television stations were added. (One hundred and thirty three stations were assumed in calculating the costs shown in Table 4.9, the same number as estimated for the earlier 1980-87 interval, although the number may very well be greater by 1990.)

ii) The incremental costs for the regional TV subsystem are about 25% lower in 1987-94 than in 1980-87, primarily because of the larger satellite used in the later time-frame.

iii) There is an apparent slight decrease in cost by using the 12/14 GHz band, but the decrease is much smaller than the probable error in cost estimation. The space portion costs of the 12/14 GHz system is less costly because of the smaller antenna used, but the ground portion is more expensive because extra antennas at the regional centres are required. The 12/14 GHz vs. 4/6 GHz trade-off is described in more detail in section 4.7.

It may be concluded from these observations that if a regional television distribution system by satellite were introduced in the early 1980's at 4/6 GHz it could be augmented or continued on the later satellite system. No significant cost penalty would be incurred by not using 12/14 GHz in the later time-frame. However, if no system for regional television distribution by satellite were introduced before 1987, the use of 12/14 GHz should be considered for this purpose. A significant factor at that time would be the relative system development costs at the two frequencies. As well, the cost of distribution by satellite would have to be compared with that of terrestrial distribution. That comparison was not made here, for reasons discussed at the beginning of section 4.5.

4.6 MINIMUM COST NETWORKS FOR OTHER TRAFFIC CONDITIONS AND OTHER NETWORK SURVIVABILITY SPECIFICATIONS

The networks discussed in sections 4.2, 4.4, and 4.5 were all synthesized to meet the preferred traffic forecast (see Appendix A) at minimum cost, with a specific network

Table 4.9

Estimated Weights and Costs of

Regional Television Addition to Satellite System

in 1987-94

Carrier Frequency, Regional TV Addition	Ground Station System Noise Temperature	Satellite Weight in Synchronous Orbit	Annual Costs, Millions of 1973 Dollars			
			Satellite Space Portion	Additional Space Portion for Regional TV	Ground Portion For Regional TV	Total For Regional TV
-	-	1050	19.1	-	-	-
12/14 GHz	29 dB ^{o}K	1410	21.6	2.5	4.0	6.5
12/14 GHz	24 dB ^{o}K	1350	21.2	2.1	4.7	6.8
4/6 GHz	29 dB ^{o}K	1465	21.9	2.8	3.8	6.6
4/6 GHz	24 dB ^{o}K	1430	21.7	2.6	4.6	7.2

survivability specification as described in section 4.4.1. Variation of these two factors has considerable effect on the network cost and the type of satellite system that should be used. The third factor that has a significant effect on the type of satellite that should be used is the network costing technique. This last factor and its consequences are discussed separately in section 4.8.

The minimum cost network to meet the maximum or exponential traffic forecast is described in section 4.6.1., and the network to meet the minimum or linear forecast is described in section 4.6.2. The variation in all three network evolutions with a change in network survivability specifications is discussed in section 4.6.3. These results are summarized in section 4.6.4.

4.6.1 MINIMUM-COST NETWORK TO MEET THE MAXIMUM TRAFFIC FORECAST

As described in section 4.2, the primary task of the satellite system is to meet the northern communication requirements, since terrestrial links to meet this need would be prohibitively expensive. Beyond that requirement, the greatest monetary gain is achieved by distributing southern nationwide television through the satellite.

The maximum forecast of northern requirements and southern television requirements in 1985 and 1990 are summarized in Table 4.10. The minimum-cost satellite system to meet either the 1985 requirement or the 1990 requirement is an RCA-type satellite with in-orbit backup. For these requirements no higher power transponders or extra transmitter tubes are required on the satellite, so the weight and costs are minimal; approximately 930 lb. in synchronous orbit and $13.2 million 1973 dollars annually for the satellite space portion. A satellite system with three in-orbit satellites such as the 8 transponder satellite being developed by American Satellite Corp. would meet the 1985 requirement, and a system with three in-orbit Anik satellites would meet the 1990 requirement, but both these systems are more expensive than that with two RCA-type satellites in orbit.

Apart from the requirements shown in Table 4.10, it is cost-effective to route a large number of voice circuits through the satellite. The minimum-total-cost network to meet the 1985 maximum traffic forecast is very similar to the network to meet the 1990 preferred traffic forecast, described in section 4.4.2. In both networks the satellite system includes three in-orbit RCA-type satellites, one acting as an in-orbit spare. About

Table 4.10

Maximum Forecast of

Northern Requirements and

Television Requirements in Southern Canada

Year	Number of Transponders For Thin-Route Voice	Number of Transponders For Northern Regional TV	Number of TV Programs To and From North	Number of TV Programs in South Only	Total Number of Transponders	
					With DITEC	Without DITEC
1985	4	3	5	8	14	20
1990	5	3	5	10	16	23

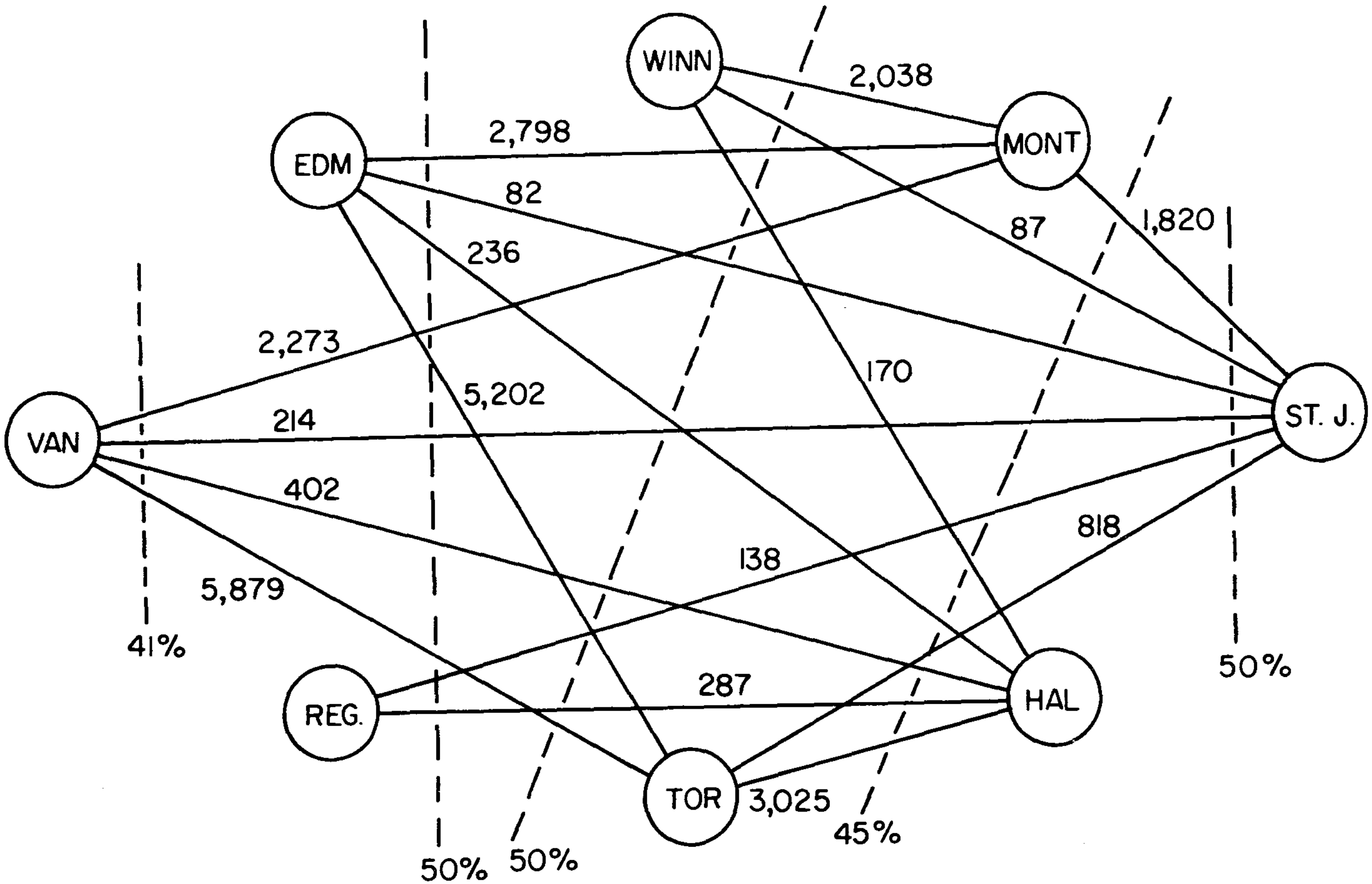


Figure 4.12

Voice Circuit Loading
Through Satellite System in 1985
In Maximum Forecast Conditions

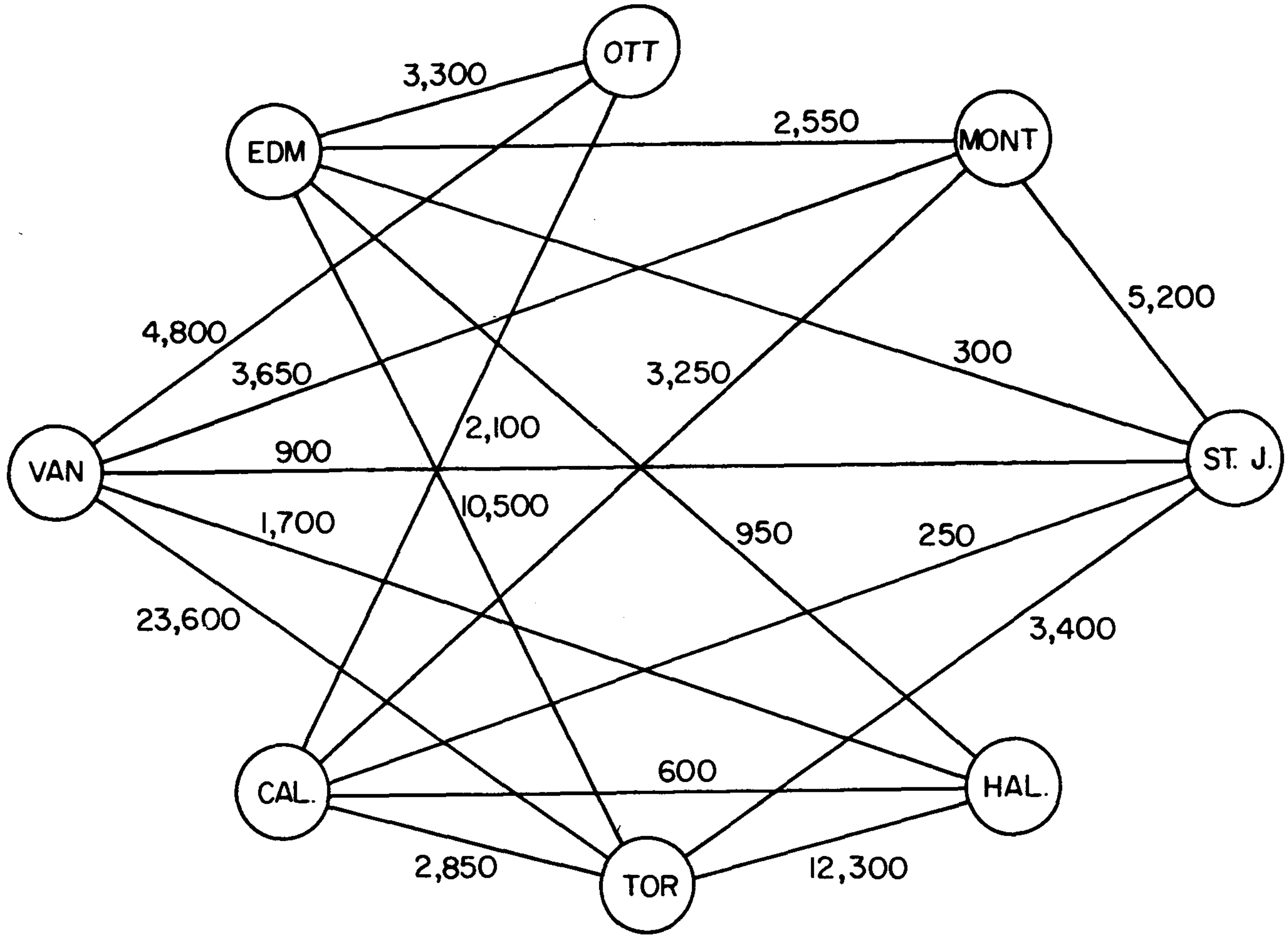


Figure 4.13

Voice Circuit Loading
Through Satellite System in 1990
In Maximum Forecast Conditions

[redacted]

Table 4.11

Voice Circuit Loading at Ground Stations in Network to Meet 1990 Maximum Forecast

Ground Station	Voice Circuit Loading
Vancouver	35,000
Edmonton	18,000
Calgary	9,000
Toronto	53,000
Ottawa	10,000
Montreal	14,000
Halifax	16,000
St. John's	10,000

[redacted]

Table 4.12

Costs and Weights of Satellite Options for the 1987-94 Time-Frame to Meet the Maximum Traffic Forecast

Traffic Carried on Satellite System				Satellite Weight In Synchronous Orbit, lb.	Launch Vehicle	Cost of Space Portion of Satellite System, Millions of 1973 Dollars	
Northern Services	Southern Nationwide Television	CBC Regional TV	Southern High Capacity Voice			Capital Cost	Annual Cost
Yes	No	No	No	540	Thor-Delta	36.1	10.7
Yes	Yes	No	No	930	Thor-Delta	47.5	13.2
Yes	Yes	Yes	No	1475	Atlas-Centaur	65.7	17.1
Yes	Yes	Yes	Yes	2345	Titan	115.2	28.4
No	No	No	Yes	1700	Atlas-Centaur	98.1	24.6
Yes	Yes	No	Yes	2000	Atlas-Centaur	106.3	26.4

[redacted]

26,000 voice circuits are routed through the satellite system, as shown in Fig. 4.12. The necessity to provide a survivable network prevents more voice circuits being routed through the satellite. As in the 1990 preferred forecast case, the additional annual cost of the satellite system to provide CBC regional television distribution in southern Canada is about 6.5 million 1973 dollars.

The maximum traffic forecast indicates very large numbers of long-haul voice circuits by 1990 (see Appendix A). With these conditions, the voice circuits routed through the satellite in the minimum-total-cost network are almost entirely determined by the network survivability specification. With the 50% limitation through two operational satellites plus an in-orbit spare, the voice circuits routed through the satellite system are indicated in Fig. 4.13. A total of about 82,000 voice circuits are routed through the satellite system; the number in each of the ground stations are indicated in Table 4.11. The only way to meet this satellite-system requirement is to use narrow $0.5^\circ \times 0.5^\circ$ spot beams at 12/14 GHz. Even with two operational satellites, and narrow spot beams, used so that the spectrum can be used several times, the amount of traffic carried in the 4/6 GHz band and the 12/14 GHz band would be limited by lack of spectrum in the early 1990's. This is because almost all voice circuits terminate in the Toronto-Ottawa-Montreal area. If 8 phase PSK and SPEC are used the satellite-system limit is about 132,000 voice circuits, 62% above the 1990 requirement, or about equal to the 1995 requirement if the same growth rate continued. Thus if traffic grows in the 1980's as fast as predicted in the exponential or maximum forecast, the 12/14 GHz band should be used exclusively for high capacity voice links.

If CBC regional television is distributed by satellite, the 4/6 GHz band should be used rather than the 12/14 GHz band. As shown in section 4.5, the costs of using one band or the other are about equal, and the higher frequency band is required for voice transmission.

The costs and the weights of the various satellite options for the 1987-94 time frame are listed in Table 4.12. The least expensive satellite system is that with all services on the same satellite. If CBC regional television is distributed on the terrestrial network, three 2000 lb. satellites are required in orbit, including the in-orbit spare. It is expected that the Atlas-Centaur will have this launch capability by 1977 . The annual cost of the space portion of the satellite system is 26.4 million 1973 dollars, or \$9.3 million greater than the satellite system without the 12/14 GHz subsystem for voice transmission. This cost is equivalent to \$113 for each for the 82,000 voice circuits, or cost low enough that the traffic carried on the satellite is limited by network survivability requirements.

[redacted]

If the CBC regional-television-distribution subsystem were added to this satellite, the satellite weight would increase to about 2350 lb. in synchronous orbit. The added space portion cost would be about $1.8 million per year. If 133 television stations in seven regions received the signals, the total subsystem annual cost would be about $5.8 million.

It is important also to examine the terrestrial network requirements, not to determine the cost of the network in detail, but to determine terrestrial system requirements. The voice circuit requirements of the TCTS terrestrial digital network requirements are shown in Fig. 4.14, and the CNCP terrestrial requirements are shown in Fig. 4.15. Both terrestrial networks will need major new systems before 1990 to meet the maximum traffic forecast.

The LD-4 coaxial cable system could be used to meet the Quebec City to Windsor requirement shown in Fig. 4.14, and could also be used effectively between Winnipeg and Calgary-Edmonton. However, it would be very expensive to lay coaxial cable between Toronto and Winnipeg, and between Calgary and Vancouver. High capacity 12 GHz digital radio systems may be required in these areas. Optic fibre systems may be available by the late 1980's, but again the high installation costs in the Rockies and across the precambrian shield would likely make high capacity radio more economical.

The voice circuit requirements of the CNCP network also dictate that CNCP install new systems. It is likely that they would install parallel systems on existing links, and possibly new links in some areas, to increase the survivability of their network. A new microwave radio system from Montreal to Edmonton through Toronto would likely meet CNCP's requirements throughout the 1990's.

4.6.2 MINIMUM-COST NETWORK TO MEET THE MINIMUM TRAFFIC FORECAST

In comparison with the networks described in section 4.6.1, or even in section 4.4, the network that meets the minimum traffic forecast at minimum cost is quite small.

The satellite system of the minimum cost network in the 1980-87 time-frame is a single Anik satellite with an in-orbit spare, similar to the Telesat system in 1973 and 1974. If possible, the Anik satellite design should be modified to allow use of all twelve transponders. To do this the capability of the

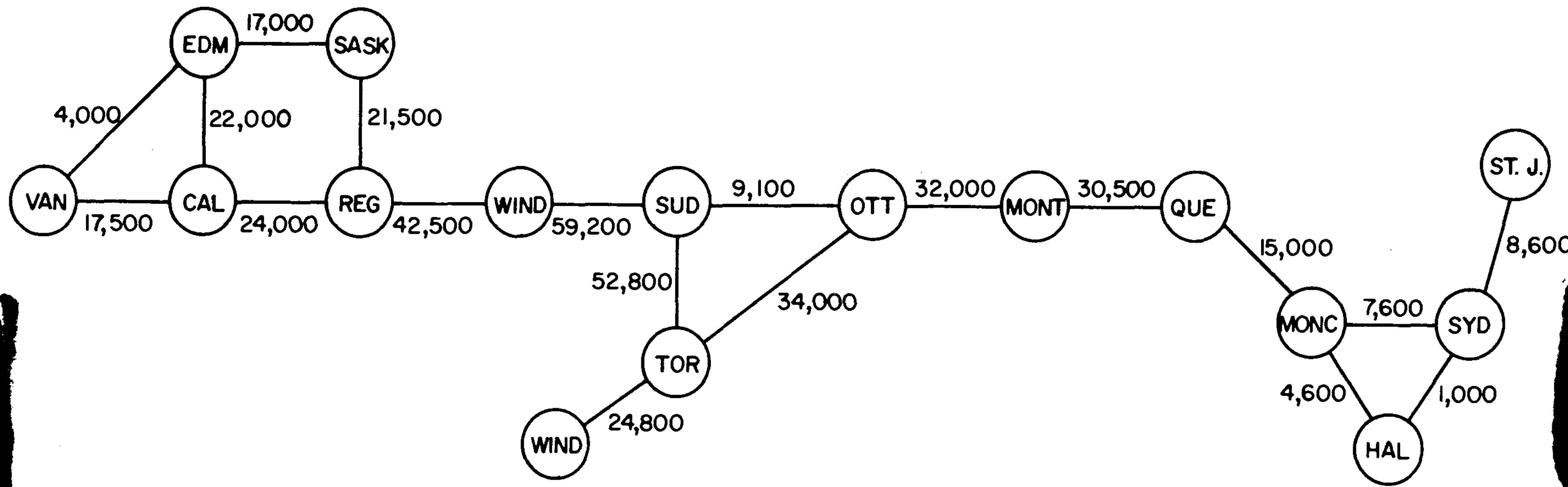


Figure 4.14

Maximum Forecast of Voice Circuit Loading
On TCTS Digital Network in 1990

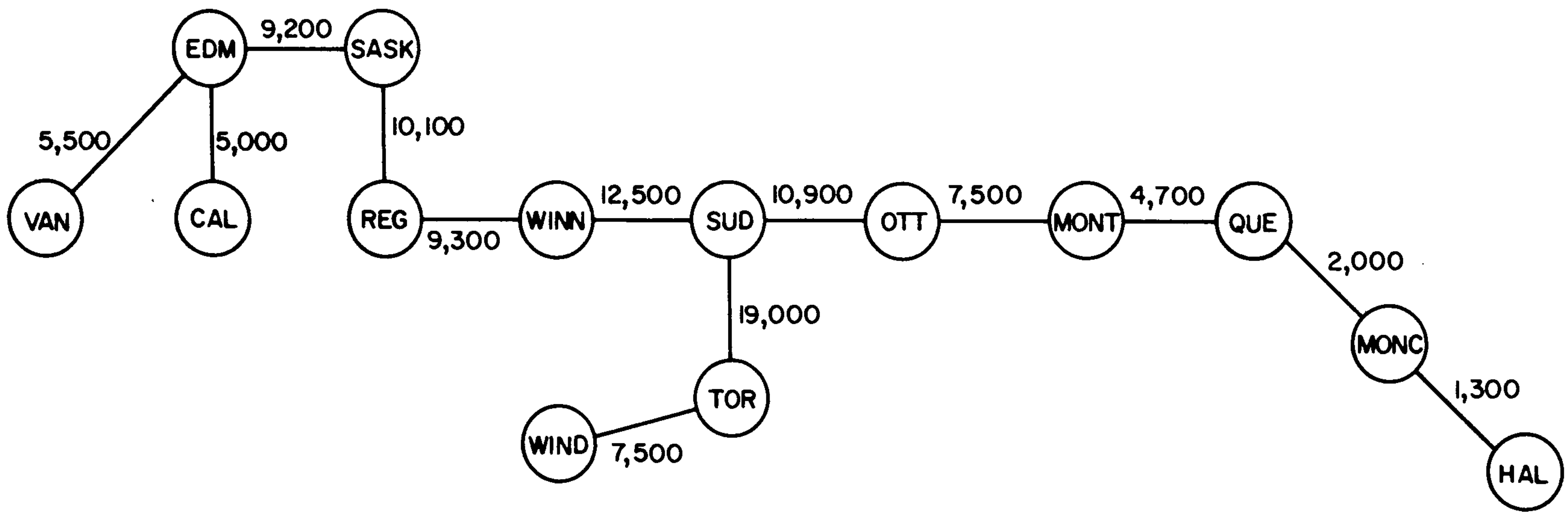


Figure 4.15

Maximum Forecast of Voice Circuit Loading
On CNCP Network in 1990

prime power system would have to be augmented, and two "spare" transponders would have to be added, as they are in the Intelsat IV design.

The traffic carried by the satellite system is shown in Table 4.13. As shown, eight transponders are required for northern services and television distribution if DITEC or an equivalent system is used. Thus four transponders are available for medium capacity voice transmission. If 4 phase PSK is used in a TDMA mode for voice transmission, and if SPEC or an equivalent source encoding technique is used, 3,200 voice circuits could be carried on the satellite. This includes an estimated 650 COTC voice circuits from Halifax to Toronto. The voice circuit links through the satellite are shown in Fig. 4.16. The relative costs of the terrestrial and satellite systems are such that it is cost-effective to put as many voice circuits through the Anik satellite as possible, but not to increase the size of the satellite to an RCA-type satellite or a dual satellite system.

In the later 1987-94 time-frame the requirements to meet the minimum traffic forecast are quite similar to the requirements to meet the preferred traffic forecast in the earlier 1980-87 time-frame. There are four possible satellite systems that may be cost-effective in the 1987-94 time-frame. These are:

i) two Anik satellites in orbit to meet the northern requirements and southern national television requirements,

ii) three American Satellite Corp. mini-satellites to carry the above plus some voice circuits.

iii) two RCA-type satellites in orbit to carry the above, plus 33% of the voice circuits,

iv) three Anik satellites in orbit to carry the above plus up to 50% of the voice circuits.

The minimum cost network includes an RCA-type satellite with an in-orbit backup. The satellite carries all the nationwide television distribution and about 4800 voice circuits. The voice circuit links through the satellite system are shown in Fig. 4.17. As in the earlier time frame, 4 phase PSK with DITEC is used for television distribution, and 4 phase PSK with TDMA and some use of SPEC is used for voice transmission.

The satellite system requirements to meet the minimum traffic forecast can be summarized by saying that a single 4/6

Table 4.13

Traffic Carried by Satellite of

Minimum Cost Network to Meet the 1985 Minimum Forecast

Traffic Type	Modulation Used	Transponders Used
Northern Thin-Route Voice	SCPC, Demand Access	2
Northern Regional Television Distribution	Analog FM	3
National Television To and From North	4 phase PSK with DITEC	2
National Television Distribution to South	4 phase PSK with DITEC	1
Southern Medium Capacity Voice	4 phase PSK with SPEC and TDMA	4

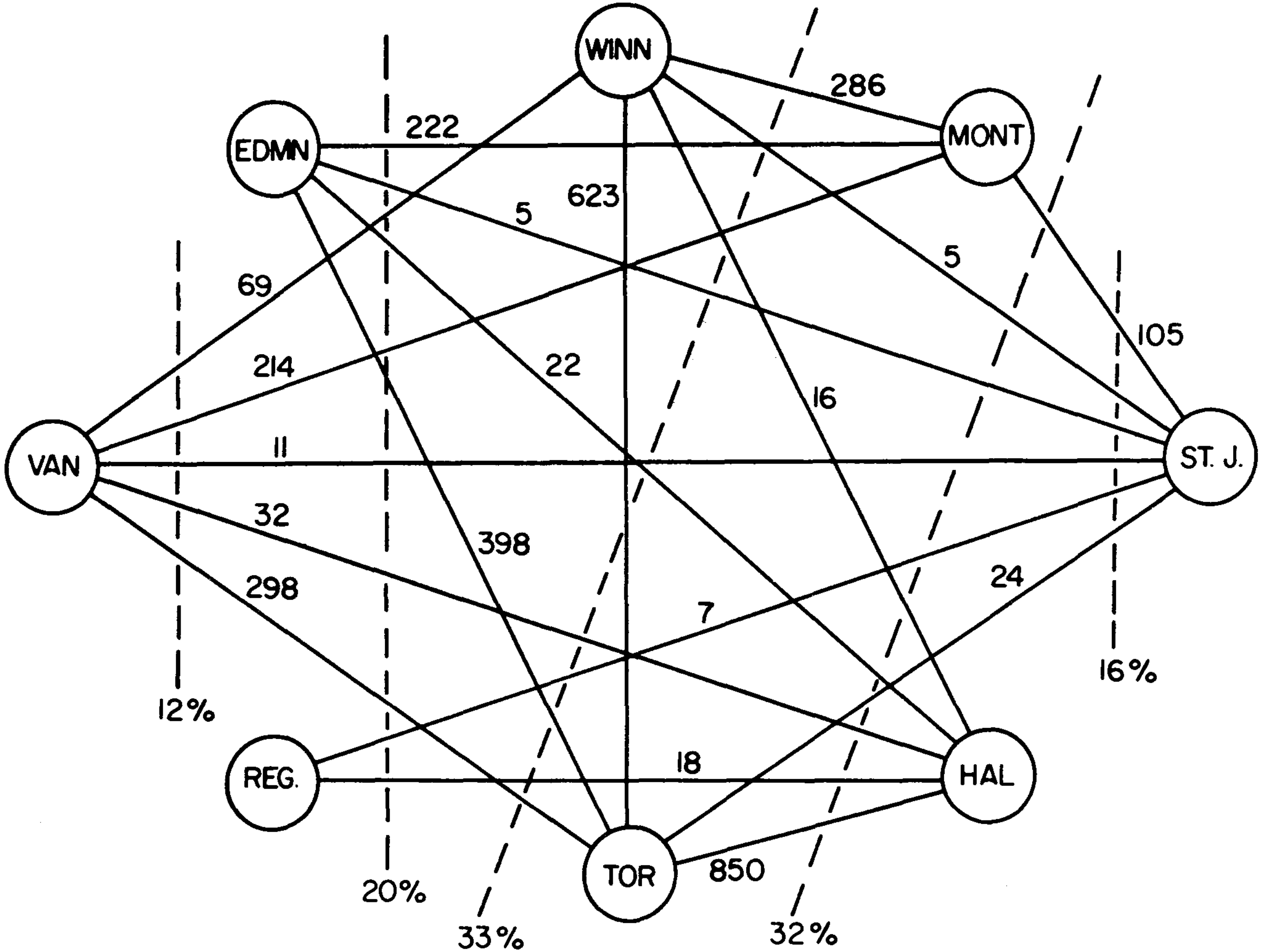


Figure 4.16

Voice Circuit Loading
Through Satellite System in 1985
In Minimum Forecast Conditions

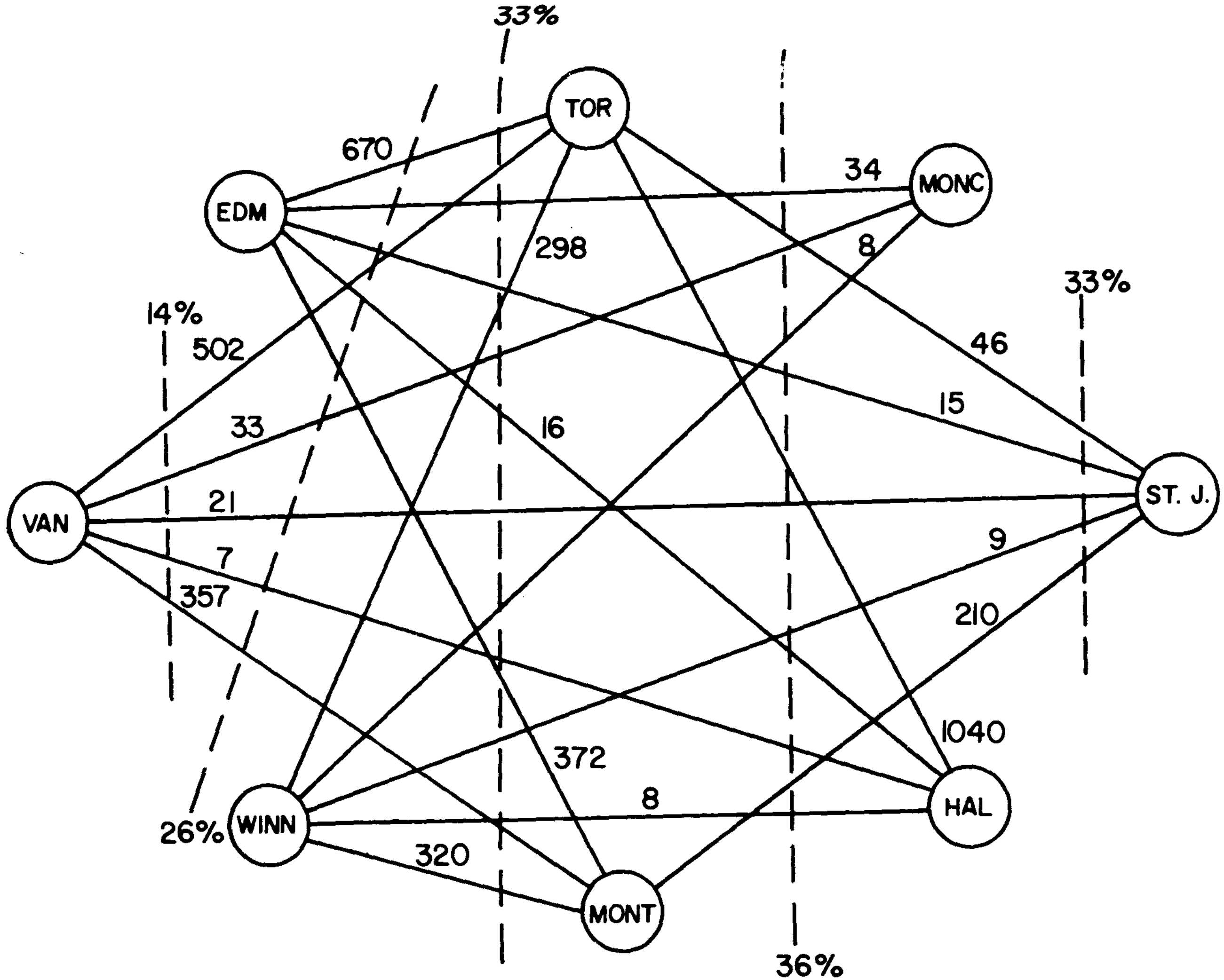


Figure 4.17

Voice Circuit Loading
Through Satellite System in 1990
in Minimum Forecast Conditions

GHz satellite with a Canada-wide beam and an in-orbit backup should be used throughout the 1980 to 1994 time-frame. In 1980-87 that satellite is an augmented Anik; in 1987-94 the satellite is a larger RCA-type satellite.

4.6.3 THE EFFECT OF CHANGES IN THE NETWORK SURVIVABILITY SPECIFICATIONS ON THE CHOICE OF SATELLITE SYSTEM

As discussed above in section 3.2.4, the network survivability of the TCTS network is 50% to 60% at the present time, except in the St. John's area where there is no survivability. It is assumed that this will be increased to about 70% to 75% throughout most of the TCTS network in the early 1980's, and to 50% in the St. John's area.

At present, the TCTS network consists mainly of two parallel coast-to-coast microwave radio systems, called the trans-Canada system and the inter-provincial system. The 8 GHz digital radio system, which will likely become part of the network in 1978 to 1980, is not an independent system in the network survivability sense, since it is an add-on to the 4 GHz analog systems and so would fail at the same time as the analog system, assuming that the failure is in the system infrastructure.

As shown in Fig. 4.18, a completely new third system is required by 1980 if the network survivability objectives are to be met. Assuming that the growth of the TCTS network is digital by 1980, the most cost-effective completely new terrestrial system is a 12 GHz digital radio one. The initial capital cost of this system is about $36,000 per mile, or $109 million 1973 dollars for a coast-to-coast system. (See Appendix B). The annual cost of such a system would be about 26 million 1973 dollars to pay amortization and M & O costs. The marginal cost of adding 9,200 voice circuits to the satellite system for 1980-87 is about 8.3 million 1973 dollars, about 32% of the initial cost of the terrestrial system. Thus it is conclusive that the third independent TCTS coast-to-coast transmission system should be part of the satellite system, since no completely new high capacity terrestrial system is economically competitive with additions to an existing satellite system.

The conventional network survivability specifications, such as those discussed in reference 6, do not consider how a satellite should be integrated into the overall network from a network survivability viewpoint. Because of the lack of either specification or precedent in a network in which the satellite system is economically competitive, we suggested a suitable

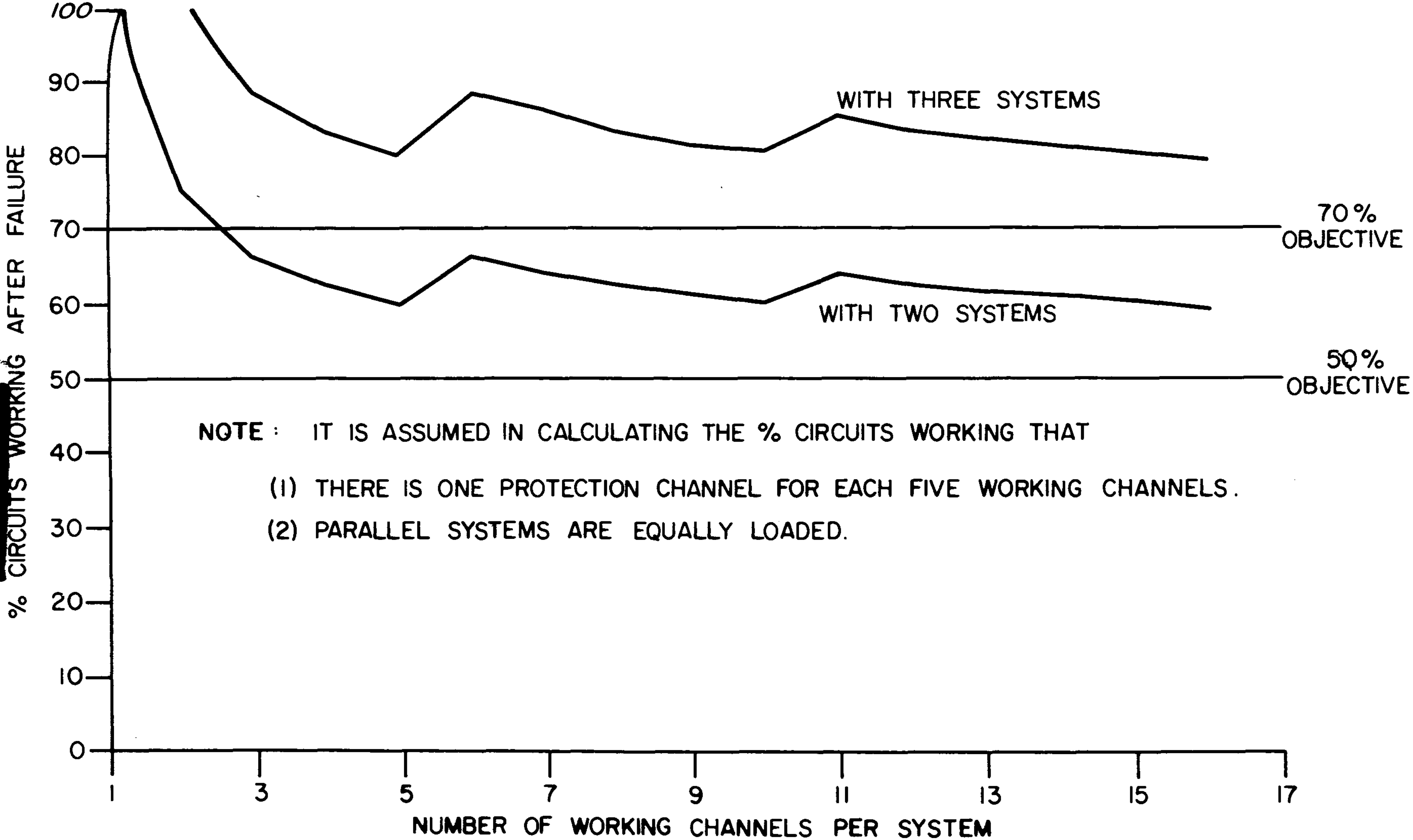


Figure 4.18

Network Survivability
By Using Protection Channels of Parallel System(s)

specification in sections 4.4 to 4.6.2. This was that not more than 50% of the voice circuits through the cross-sections in Fig. 4.1 if the satellite system has three identical orbiting satellites, and not more than 33 1/3% of the voice circuits if it has two orbiting satellites.

In this section four such specifications are considered to determine the sensitivity of the choice of satellite system to the specification used. The specifications compared are:

i) up to 50% of the voice circuits through a single satellite with in-orbit backup,

ii) up to 50% of voice circuits through a system with dual operational satellites with in-orbit backup, or up to 33 1/3% through a single satellite with in-orbit backup, (this was the specification used previously, and is the baseline system in the sensitivity analysis),

iii) up to 33 1/3% through a single operational satellite system with in-orbit backup, without option to go above 33 1/3% with more satellites,

iv) Up to 33 1/3% through a dual operational satellite system with in-orbit backup.

Specification (i) is a very relaxed one, and would result in a minimum cost network, but is not likely to be adequate. Specification (ii) is considered adequate; it was used in sections 4.4 to 4.6.2 above. Its advantage over (i) is that when two satellites plus an in-orbit spare are used the satellite system itself has a survivability of at least 50% immediately and 100% after the in-orbit spare becomes operational. Specification (iii) sets limits on the satellite traffic in much the same way as one of the two terrestrial systems, without considering the self-survivability of a dual satellite system. Specification (iv) is a very conservative one; it limits the satellite traffic to the same as that of one of the two terrestrial networks, and yet requires that the satellite system have considerable self-survivability. These four possible specifications are certainly not the only possible ones, but we believe they span the range of possible specifications. It is very unlikely that greater than 50% of the traffic would be routed through a single satellite system. At the other extreme, close to 33 1/3% of the traffic would have to be routed through the satellite if it were used to improve the overall TCTS network survivability. from a network survivability viewpoint there would be no reason not to do that if a dual satellite system were used.

Let us consider the minimum-cost network to meet the requirements of the 1985 preferred forecast subject to each of the above four specifications. The satellite systems in the four situations are as follows:

With specification (i)	Augmented RCA-type satellite
With specification (ii)	Dual-augmented Aniks
With specification (iii)	RCA-type satellite
With specification (iv)	Dual Aniks

The characteristics and costs of the networks when each of the above four satellite systems is used are shown in Table 4.14. The network with a single Anik satellite, plus in-orbit spare, with all southern voice traffic on the terrestrial network, is also included for comparison.

The total network annual costs are very similar for networks subject to each of the above four survivability specifications, and also for the network with no voice traffic by satellite. The total variation in costs from putting no voice by satellite to putting up to 50% on a single satellite with backup is only 2.7 million 1973 dollars, or 4% of the total network costs. Note that the cost of the overall network would be much higher if a third TCTS terrestrial system were built to provide 70% or greater network survivability without using the satellite system.

In the 1987-94 time-frame the potential traffic through the satellite system is over twice that in the earlier period. The minimum-cost solutions in the same four situations have the following satellite systems:

With specification (i)	a hybrid satellite with 4/6 GHz for television distribution and 12/14 GHz for voice transmission
With specification (ii)	dual RCA-type satellites
With specification (iii)	a smaller hybrid satellite, with the same use of the two frequency bands.
With specification (iv)	dual augmented Anik satellites

The characteristics and costs of these four networks to meet the requirements of the preferred forecast in 1990 are summarized in Table 4.15. Also included, as above, is the network with all voice in southern Canada through the terrestrial network, with a single RCA-type satellite to meet northern requirements and to distribute nationwide television programs.

Table 4.14

Characteristics and Costs of Networks

To Meet Requirements of 1985 Preferred Forecast

With Various Network Survivability Requirements

Voice Traffic Through Satellite	Satellite System Type	Satellite	Satellite Weight in Synchronous Orbit, lb.	Network Annual Costs In 1985, Millions of 1973 Dollars		
				Satellite System	Terrestrial Networks	Total Network
≤ 50%	Single	Augmented RCA	1100	25.6	40.9	66.5
≤ 50%	Dual	Augmented Anik	650	26.7	40.9	67.6
≤ 33 1/3%	Single	RCA-Type	1050	24.4	42.9	67.3
≤ 33 1/3%	Dual	Anik	590	26.3	42.9	69.2
0	Single	Augmented Anik	540	18.5	50.2	68.7

Table 4.15

Characteristics and Costs of Networks

To Meet Requirements of 1990 Preferred Forecast

With Various Network Survivability Requirements

Voice Traffic Through Satellite	Satellite System Type	Satellite	Satellite Weight in Synchronous Orbit, lb.	Network Annual Costs in 1995, Millions of 1973 Dollars		
				Satellite System	Terrestrial Networks	Total Network
≤50%	Single	Hybrid	1580	33.8	63.2	97.0
≤50%	Dual	RCA-Type	1050	34.6	62.9	97.5
≤33 1/3%	Single	Hybrid	1520	31.6	67.3	98.9
≤33 1/3%	Dual	Anik	655	29.2	70.2	99.4
0	Single	RCA-Type	950	25.5	77.1	102.6

It should be noted here that when a single satellite is used for northern services, southern television distribution, and 33 1/3% or more of southern voice traffic, there is not enough spectrum available at 4/6 GHz to use this band only in the satellite. Use of the spot beams at 4/6 GHz is of little value, because most voice traffic which is routed through the satellite terminates at either Toronto or Montreal, and because of the high cost of satellite antennas for spot beams at 4/6 GHz. The solution, of course, is to use 12/14 GHz spot beams for voice transmission and 4/6 GHz for television distribution and voice transmission to remote areas. This point will be discussed in further detail in section 4.7.

As shown in Table 4.15, the total network costs decrease as more voice circuits are routed through the satellite, and as less requirements are placed on the survivability of the network. The reduction in network costs by routing large quantities of voice circuits through the satellite is about $5 million, about 5% of total network annual costs. The gain would be much greater if the alternative were to build a new coast-to-coast terrestrial link.

4.6.4 THE DUAL ANIK SATELLITE SYSTEM: A BALANCE OF CONFLICTING REQUIREMENTS

Satellite-terrestrial networks have been determined for 1985 and 1990 to meet the expected or preferred traffic forecast, the linear or minimum forecast, and the exponential or maximum forecast. The satellite systems of these six networks are shown in Table 4.16. The different satellite systems to meet the various survivability specifications at minimum total network annual costs are not shown in Table 4.16. However, satellite systems with dual operational satellites are preferred to systems with a single operational satellite, since their operation during solar transit and solar eclipse is much better, and the self-survivability of the satellite system is much better. (Both types of system have an in-orbit spare in addition to the operational satellite or satellites). The most cost-effective dual satellite system is a dual Anik system, whether the maximum traffic through the satellite is 50% or 33 1/3%. In the former case a slightly larger Anik-type satellite is used, with an $0.4 million extra satellite system cost but with a $1.6 million smaller total network cost. It is expected that this satellite system will be used in the 1980-87 period.

Let us consider the dual Anik satellite system in 1980-87 from three viewpoints:

Table 4.16

Satellite Systems of

Minimum-Total-Cost Networks

Traffic Forecast	Time-Frame 1980-87	Time-Frame 1987-94
Maximum	Dual RCA-type	Dual Hybrid (12/14 GHz for voice)
Preferred	Dual Aniks	Dual RCA-type
Minimum	Single Aniks	Single RCA-type (or Dual Aniks)

i) compatibility with the present network, and with possible systems in the 1987-94 period,

ii) network annual costs in different traffic-growth situations,

iii) network survivability.

The dual Anik satellite system is of course compatible with the present Telesat system. Telesat launched two Aniks in 1973 and 1974, and plan to launch a third in 1975. Thus Telesat already has a dual Anik system, although it is not used in the same way that the proposed dual Anik system for 1980-87 would be used. Additions to the present Telesat ground stations, apart from the electronic equipment to handle the extra traffic, would be a second antenna at Allan Park, Lake Cowichan, and each of the present NTV stations. A 33' parabolic antenna would be adequate, but a toroidal antenna with similar gain would improve the system's performance.

A dual Anik system in 1980-87 would be compatible with cost-effective satellite systems for all three traffic forecasts in the later 1987-94 time-frame. If the current preferred or expected traffic forecast were still the preferred forecast in about 1984, it is likely that a dual RCA-type satellite system would be used in the late 1980's as a replacement for the dual Anik system. No change in the ground stations would be required for this change; the Anik satellites would simply be replaced by RCA-type satellites when required.

If the traffic growth decreased in the 1980's, so that the minimum forecast describes the traffic in the mid and late 1980's, the satellite system in the minimum-cost network for 1987-94 would be a simple RCA-type satellite to carry northern traffic and nationwide television distribution. However, a dual Anik system could meet this same requirement with superior performance at slightly greater cost, as shown in section 4.4.1. In fact, if the extra antennas were considered "existing equipment" in doing a similar study in 1982, the dual Anik system would likely be minimum cost. Such an evolution would be very simple to carry out; Anik satellites would simply be replaced when required.

The dual Anik system in 1980-87 would also be compatible with the satellite system to meet maximum traffic conditions in the 1987-94 time-frame. As indicated above in section 4.6.2, the most cost-effective system to meet the 1990 maximum traffic requirements is a dual hybrid system. The 4/6 GHz portion of such a system would be very similar from a network viewpoint to an RCA-type satellite, and would use the dual-antenna ground stations of the dual Anik system. Voice traffic could be transformed gradually from the 4/6 GHz portion of the satellite system to the 12/14 GHz portion of the system as the traffic increased and as the ground stations of the 12/14 GHz system were introduced. This gradual transfer is particularly easy, because the 12/14 GHz transponders are used as dedicated links between two locations. Since the 4/6 GHz subsystem has a Canada-wide beam, capacity of the 4/6 GHz system that would be released by introduction of a 12/14 GHz link could be used anywhere in the country.

Thus a dual Anik satellite system is compatible with the present Telesat system and with any system that might be introduced in the late 1980's.

Let us now concentrate on the 1980-87 time-frame, and determine the cost penalty of using the dual Anik system rather than some other system.

In preferred traffic forecast conditions, the dual Anik system is almost a minimum-cost system. A single RCA-type satellite with in-orbit spare is slightly less expensive, but the dual Anik system is preferred, for reasons described in section 4.4.1.

In minimum traffic forecast conditions in the 1980's, a dual Anik system would provide more capacity than could be used cost-effectively. With a dual Anik system in orbit more traffic could be routed through the satellites than through a single Anik system, but the extra use of the satellite would be limited by the network survivability constraint. The extra use of the satellite would not pay for the extra cost; a net increase of about $3 million annual costs would be the penalty for choosing too large a system. It should be noted, however, that the decision to purchase and launch the third Anik for the 1980-87 period can be delayed several years, because the satellite to be launched in 1975 should be available until mid 1982.

In contrast, a dual Anik system is not large enough to meet the requirements described by the maximum forecast. It is not possible to place a fourth Anik in orbit, because Canada does not have four orbit locations. The only alternative is to route traffic terrestrially until a larger satellite is launched in the mid 1980's. The penalty for using two Anik satellites where two RCA-type satellites should be used would be about 4.5 million 1973 dollars annual cost in 1985.

From a network survivability viewpoint, the dual Anik system is without equal for the 1980-87 period. A proven system would be used by a carrier with long experience in its use, and so both component and operator failures should be minimized. From a network viewpoint, the satellite system itself has a network survivability of at least 50%, and a possible 100% if toroidal antennas were used as second antennas.

Thus a dual Anik system is a very cost-effective satellite system for the early 1980's. It is compatible with the present system, and with almost any system that may be used in the late 80's and early 90's. It is a very reliable system from a satellite failure viewpoint, a possible operation failure viewpoint, and a network survivability viewpoint. From a network cost viewpoint it is near minimum cost in the most likely traffic conditions, and the penalty of choosing it is within 3 to 4 million 1973 dollars in extreme traffic conditions.

4.7 THE COST-EFFECTIVE USE OF THE 12/14 GHz BAND

The present Anik system would have a capacity of 4,800 voice circuits or 10 television programs if the satellite were used only for high capacity voice transmission or television distribution. There are several ways to increase the capacity of the next system beyond this basic amount. These include:

i) augmenting the satellite so that all transponders can be used during solar eclipse and at the end of the satellite's planned lifetime.

ii) use of source encoding techniques and different modulation methods to increase the effective capacity (see section 4.3).

iii) use of both polarizations, either both horizontal and vertical or both right and left circular, to double the capacity, (this is applicable when digital transmission is used).

iv) use of more than one operational satellite to double or perhaps triple the system capacity,

v) use of the same frequency and polarization more than once, by employing high-resolution antennas on the satellite.

vi) use of both the 4/6 GHz band and the 12/14 GHz band, each with a 500 MHz bandwidth, either on the same satellite or on seperate satellites in the same orbit position.

[redacted]

By using techniques (i) to (iv) at 4/6 GHz (or at 12/14 GHz), the capacity of the satellite system can be increased to orbit 65,000 voice circuits or 96 television programs. This is the maximum capacity of a satellite system such as the dual RCA-type satellite system to meet the exponential forecast in 1985.

If a satellite system with a higher capacity is required techniques (v) or (vi), or both, must be used.

In this section we discuss the cost-effective use of the 4/6 GHz band and the 12/14 GHz band, both when the total satellite-capacity requirement is below 65,000 voice circuits and when it is above this value. Let us first consider the relative advantages of the 4/6 GHz band and the 12/14 GHz band to augment the Canadian domestic satellite system. The advantages of a 4/6 GHz system are:

i) Many ground stations have been constructed both in southern and northern Canada as part of the present Telesat system. These ground stations use the 4/6 GHz band, and could use the 4/6 GHz band in the 1980's with negligible refurbishment. In contrast, new antennas would be required if they were converted to 12/14 GHz.

ii) There is negligible atmospheric attenuation of the radiated signal at 4 GHz and 6 GHz. In contrast, the attenuation at 12 GHz and 14 GHz during a heavy rain storm is several decibels.

In contrast, there are several reasons for using the 12/14 GHz band. These include:

i) There is no flux-density limitation on the signal radiated from the satellite at 12 GHz. (At 4/6 GHz there is a limitation of not more than -142 dBW/m^2 in any 4 KHz band at high angles of arrival, or -152 dBW/m^2 at low angles of arrival). Thus at 12/14 GHz there is no constraint on the most cost-effective trade-off between transmitter power and ground antenna size in designing a satellite system.

ii) At 12/14 GHz a satellite system has priority over a new terrestrial radio system when there is a possibility of radio interference between the two systems. Since there are no large 12 GHz or 14 GHz terrestrial radio systems in Canada at present, there are essentially no restrictions on the location or power of 12/14 GHz ground stations. In contrast long

[redacted]

backhaul links are necessary at all 4/6 GHz ground stations in southern Canada to avoid interference with existing 4 GHz and 6 GHz terrestrial analog radio systems.

iii) Because the wavelength of a 12 GHz signal is about one third that of a 4 GHz signal, a spot-beam antenna on a satellite is much smaller and lighter at 12 GHz than an antenna of similar gain at 4 GHz. The result is that a satellite is lighter and so less costly if 12/14 GHz rather than 4/6 GHz is used with spot beams.

The problem of attenuation of the 12 GHz and 14 GHz signal due to rain is an important one, in that the additional signal strength required to overcome the rain can result in a much higher satellite weight and therefore higher satellite cost. The additional signal strength required is of course dependent on the amount of outage tolerated in the system. The permissible outage time for a system which is carrying long-haul trunk telephone circuits and national television programs is 0.01% or 53 minutes per year. In reference (5) it is shown that an 8 dB signal strength margin is required to meet this specification. The corresponding signal strength margin used by Telesat and other satellite operators at 4/6 GHz is 3 dB. With these margins, the system carrier-to-noise ratios required at 4/6 GHz, and at 12/14 GHz, for telephony and for television transmission, are shown in Table 4.17.

The significance of the figures shown in Table 4.17 becomes clearer when one considers the powers required at the satellite transponder outputs to meet the requirements shown in Fig. 4.17. Several illustrative examples are shown in Table 4.18. If a 0.5° by 0.5° spot beam or a 1.7° by 0.7° regional antenna beam is used the required transmitter power is less than 2 watts when either frequency band is used, so the extra "weather margin" at 12 GHz does not impose a large weight penalty on the satellite. In contrast, if 12 GHz is used for digital transmission through a Canada-wide antenna beam, transmitters with about 20 watts output are required. Such transponders are available; one is being tested on the CTS satellite. However, the transponder weight, battery weight, prime power system weight, etc, is considerably greater when 20 watt transponders rather than 5 watt transponders are used. Thus there is considerable satellite weight and cost penalty when 12 GHz is used for Canada-wide coverage, but not when it is used through spot beams.

A second significant difference between a spacecraft using the 12/14 GHz band and a spacecraft meeting the same requirement

Table 4.17

Required System Carrier to Noise Ratios

Service	Modulation Used	Carrier Frequency, GHz	System Carrier-to-Noise Ratio, dB
Voice	4 phase PSK	4/6	17.6
Voice	8 phase PSK	4/6	23.3
Television	4 phase PSK/DITEC	4/6	16.6
Television	Analog FM	4/6	13.5
Voice	4 phase PSK	12/14	22.6
Voice	8 phase PSK	12/14	28.3
Television	4 phase PSK/DITEC	12/14	21.1
Television	Analog FM	12/14	17.5

Table 4.18
Required Transponder Output Power

Service	Modulation Used	Carrier Frequency GHz	Transponder Bandwidth, MHz	Satellite Antenna Pattern	Ground Antenna Diameter	System Noise Temp.	Transponder Power, watts
TV	FM	4	36	8° x 3°	28'	22 dB	3.5
TV	FM	12	36	8° x 3°	30'	22	7.7
TV	4 phase PSK	4	36	8° x 3°	33'	22	5.1
TV	4 phase PSK	12	36	8° x 3°	30'	22	17.5
Voice	4 phase PSK	4	36	8° x 3°	33'	22	6.5
Voice	4 phase PSK	12	36	8° x 3°	30'	22	24.8
Voice	8 phase PSK	4	36	8° x 3°	97'	22	2.8
Voice	8 phase PSK	4	36	1.7° x 0.7°	33'	22	1.2
Voice	8 phase PSK	12	36	1.7° x 0.7°	30'	22	4.6
Voice	4 phase PSK	4	36	1.7° x 0.7°	33'	22	0.32
Voice	4 phase PSK	12	36	1.7° x 0.7°	30'	22	1.4
Voice	8 phase PSK	4	36	0.5° x 0.5°	33'	22	0.25
Voice	8 phase PSK	12	36	0.5° x 0.5°	30'	22	0.96

[redacted]

by using the 4/6 GHz band is the antenna system of the spacecraft. Because the wavelength of a 12 GHz radio wave is one third that of a 4 GHz radio wave, the reflector of a 12 GHz antenna is only one ninth the area and weight of an equivalent antenna at 4 GHz. The estimated weight of various antenna reflectors are shown in Table 4.19. The advantage of a 12 GHz system is of little importance when an 8 by 3 or 8 by 2 Canada-wide beam is used. However, it is a significant advantage when a regional beam is used, and has over-riding importance if 0.5° by 0.5° spot beams are used. This result complements the conclusion reached by considering the transmitter requirements in the two bands, that

i) 4/6 GHz should be used when Canada-wide coverage is required,

ii) 12/14 GHz should be used when high-resolution spot beams are required.

iii) both frequency bands should be considered when regional antenna beams are used.

4.7.1 COST-EFFECTIVE USE OF 4/6 GHz and 12/14 GHz TO MEET REQUIREMENTS OF THE 1990 PREFERRED FORECAST

The potential uses of the 12/14 GHz band in satellites for the Canadian long-haul trunk network were examined by comparing the cost-effectiveness of 4/6 GHz satellites, 12/14 GHz satellites, and hybrid (4/6 GHz and 12/14 GHz) satellites to meet the requirements of the 1990 preferred forecast. We recall from sections 4.4 and 4.6 that the traffic through the satellite in the network to meet the 1990 preferred forecast is limited primarily by the network survivability constraint. Thus the traffic through the different satellite options will be very similar. However, it may not be identical in the different options because of the following important differences in the satellite systems.:

i) The cost of a <u>new</u> GHz ground station is considerably greater than <u>a new</u> 12/14 GHz ground station, because of the backhaul problem at 4/6 GHz.

ii) The cost of satellites with Canada-wide antenna beams is considerably more when 12/14 GHz is used than when 4/6 GHz is used. Because of this a 12/14 GHz satellite subsystem would likely only include high-capacity voice links with dedicated transponders, rather than shared use of transponders

[redacted]

Table 4.19

Estimates of

Antenna Reflector Weights

Antenna Pattern Subtended Angles	Antenna Gain, dB	Reflector Weight, lb.	
		For 4 GHz Use	For 12 GHz Use
$8^{\circ} \times 3^{\circ}$	27.0	4.4	0.5
$2.5^{\circ} \times 1.2^{\circ}$	36.0	35	3.9
$1.2^{\circ} \times 1.2^{\circ}$	39.2	73	8.1
$1.7^{\circ} \times 0.7^{\circ}$	40.1	88.5	9.8
$0.5^{\circ} \times 0.5^{\circ}$	46.8	421	46.7

with TDMA, which require Canada-wide coverage for proper operation.

The satellite system will carry six distinct types of traffic, excluding regional television distribution in southern Canada. These are:

i) thin-route voice transmission to, from, and within northern Canada,

ii) regional television distribution within northern Canada,

iii) nationwide television distribution both in southern Canada and between northern and southern Canada,

iv) nationwide television distribution in southern Canada only,

v) medium capacity voice links, with capacities of tens to hundreds of voice circuits, between southern communities and possibly including the larger northern communities as their communication requirements increase,

vi) high-capacity voice links with thousands of voice circuits capacity between large cities.

It is assumed that the satellite system will carry up to 50% of the southern voice traffic, and will have two operational satellites plus an in-orbit spare and a second spare on the ground, (see section 4.6.3 above). If a satellite carries only television and thin-route voice traffic, it is assumed that two in-orbit satellites and a third satellite on the ground are sufficient. Costs would be slightly higher if three orbiting satellites plus a fourth on the ground were required.

Eight possible satellite systems are considered as part of the network to meet the 1990 preferred forecast. They are distinguished by:

i) what types of traffic are carried on each of the two frequency bands 4/6 GHz and 12/14 GHz,

ii) whether separate satellites for the two frequency bands or a single hybrid satellite are used.

The eight systems considered are shown in Table 4.20.

Table 4.20

Comparison of Costs of Various Satellite Options

to Meet the 1990 Preferred Forecast

Option	1	2	3	4	5	6	7	8
Frequency Band (GHz) For								
Thin-Route Voice	4/6	4/6	4/6	4/6	4/6	4/6	4/6	12/14
Northern Regional TV	4/6	4/6	4/6	4/6	4/6	4/6	4/6	12/14
North-South TV	4/6	4/6	4/6	4/6	4/6	4/6	4/6	12/14
South-only TV	4/6	4/6	4/6	12/14	12/14	12/14	12/14	12/14
Medium Capacity Voice	4/6	-	-	4/6	4/6	-	-	-
High Capacity Voice	4/6	12/14	12/14	4/6	4/6	12/14	12/14	12/14
Specialized Satellites	No	Yes	No	Yes	No	Yes	No	No

Table 4.20 (cont'd)

Comparison of Costs of Various Satellite Options

to Meet the 1990 Preferred Forecast

Option	1	2	3	4	5	6	7	8
Satellite Weight in orbit, lb.								
4/6 GHz Satellite	960	940	-	825	-	520	-	-
12/14 GHz Satellite	-	540	-	690	-	950	-	1175
Hybrid Satellite	-	-	1008	-	1130	-	1150	-
Annual Cost, Millions of 1973 Dollars								
Satellite Space Portion	18.4	28.6	18.8	29.9	19.7	28.8	19.9	21.1
Satellite Ground Stations	16.2	18.4	18.4	19.4	20.3	17.9	17.9	16.2
Terrestrial Network	62.9	63.2	63.2	62.9	62.9	63.2	63.2	63.2
Total Network	97.5	110.2	100.4	112.2	102.9	111.9	101.0	100.5

The total number of voice circuits in southern Canada which are routed through the satellite system is almost the same in all cases, about 21,000 voice circuits, limited by the network survivability specification. The only difference in the voice circuits carried in the different options is that when 12/14 GHz is used for voice no medium-capacity voice-circuit links are used through the satellite. This is because it is more cost-effective to include more high-capacity links with spot beams at 12/14 GHz than a system that uses TDMA medium-capacity transmission through a Canada-wide beam. (The converse is true when 4/6 GHz is used.) The net result is slightly higher terrestrial-network cost when 12/14 GHz is used for voice.

The weights of the satellites and annual costs of the networks for the eight options are shown in Table 4.20. The following observations can be made of the data shown in Table 4.20:

i) In almost all cases the satellites can be launched with a Thor-Delta launch vehicle or the augmented Thor-Delta that has been developed for RCA. An Altas-Centaur or its equivalent may be required for 3 of the 11 satellites.

ii) The network with three RCA-type satellites has minimum cost, although four other possibilities have annual cost within $5.4 million or 5.5% of the minimum cost solution. Note, however, that the minimum cost solution is the most compatible with the network in the earlier 1980-87 time-frame, so its advantage would be greater than 5 1/2% if present value of total expenditures were evaluated,

iii) It is very costly to use separate satellites for different services at different frequencies, as in options 2, 4, and 6. The space portions of the satellite systems cost about 50% more, resulting in a 10% increase in total network costs.

iv) The most cost-effective use of the 12/14 GHz band is for high-capacity voice links through spot beams with a hybrid satellite. A relatively smooth network evolution could be carried out if this option were selected. A system using 12/14 GHz exclusively has a similar annual cost, but would be much more difficult to initiate. Moreover, choice of option eight would cause a second difficult conversion in the 1990's when the 12/14 GHz band (or the 18/30 GHz band) is required for voice transmission.

[redacted]

4.7.2 CHOICE BETWEEN 4/6 GHz AND 12/14 GHz FOR REGIONAL TELEVISION DISTRIBUTION

The addition of the capability to distribute CBC regional television in southern Canada, as an addition to the Anik-like and RCA-type satellites, was described in section 4.5 above. There is no significant cost differential between use of the 4/6 GHz band and the use of 12/14 GHz for regional TV distribution if digital transmission and efficient source encoding is used. (Use of DITEC encoding equipment was suggested in reference (4) for a television distribution system exclusively at 12/14 GHz). The addition of regional TV to each of the five attractive options of Table 4.20 is examined here. (The five attractive options are options 1, 3, 5, 7 and 8, all those which did not use separate specialized satellites.)

The cost of the addition of a regional TV subsystem to these five satellite systems is shown in Table 4.21. In each case it was assumed that low cost ground stations are used and that the frequency band used for regional TV is the same as that used for nationwide TV. (The alternatives are more expensive in each case). Cost of the regional TV addition varies between $5.8 million and $6.8 million per year. Again, option 1, the 4/6 GHz, is least expensive. The differences in annual cost between the five options shown in Table 4.21 are quite small in terms of the total network cost. However, the 4/6 GHz system is most compatible with the satellite system which precedes it. As a result, considerable capital expenditure would have to be made about 1987 if one of the alternate systems were chosen. Because of this the present value of the costs of the systems using 12/14 GHz would be significantly greater than that of the 4/6 GHz system.

4.7.3 SUMMARY OF THE SALIENT FEATURES OF COST-EFFECTIVE SATELLITE SYSTEMS

The satellite system issues that were discussed in this section are:

a) The most cost-effective use of the 4/6 GHz and 12/14 GHz bands,

b) The use of specialized satellites, a single composite satellite, or several identical satellites.

The satellite frequency bands should be used as follows:

[redacted]

Table 4.21

Additional Annual Costs for the Distribution

of Some CBC Regional TV Programs by Satellite

Basic Satellite Option (Table 4.20)	Frequency Band For Regional TV	Network Annual Costs in 1990, Millions of 1973 Dollars			
		Basic Satellite System	Additional For Regional TV By Satellite	Terrestrial Network	Total
1	4/6 GHz	34.6	6.6	62.9	104.1
3	4/6 GHz	37.2	6.8	63.2	107.2
5	12/14 GHz	40.0	6.3	62.9	109.2
7	12/14 GHz	37.8	6.2	63.2	107.2
8	12/14 GHz	37.3	5.8	63.2	106.3

i) 4/6 GHz should be used exclusively until the required satellite capacity is greater than that available with two operational omni-beam satellites using both horizontal and vertical polarization. (The capacity of this system is roughly four times that of the present Anik system.)

ii) The most cost-effective use of 12/14 GHz is to establish the following high-capacity voice links:

Toronto	to	Edmonton and Vancouver
Montreal	to	Edmonton and Vancouver
Halifax	to	Toronto
St. John's	to	Montreal

This should be done only after the 4/6 GHz system is saturated, but would gradually carry all the satellite voice traffic allowed by the network survivability constraints.

iii) Nationwide TV distribution and regional TV distribution in the north should be done with a 4/6 GHz system.

iv) The second important use of 12/14 GHz would be in a system with thousands of ground stations, where the most cost-effective satellite EIRP exceeds that allowed in the 4/6 GHz band. (Services of this kind were not considered in the DLDCNS.)

v) The frequency band for regional TV distribution can be chosen based on where there is least demand for spectrum for other services. It is probable that this band will be the 4/6 GHz band.

With regard to the specialization and multiplicity of satellites in orbit, it has been determined that:

i) It is very expensive to use specialized satellites, such as different satellites for different frequency bands. The penalty incurred if this approach is taken is about ten million dollars per year.

ii) The least costly satellite system is that with one large operational satellite and an in-orbit spare.

iii) The cost penalty to have a system with the same total capacity but with two identical smaller satellites plus one in-orbit spare is quite small. This system is more survivable than one large satellite, it operates much better during solar eclipse and solar transit, and is more adaptable to unexpected increases or decreases in traffic. For this reason it is recommended over either of the other two classes of system.

4.8 AN ALTERNATIVE NETWORK COSTING PROCEDURE AND ITS RESULTING NETWORK EVOLUTION

4.8.1 MARGINAL COSTING

The network evolution as described in sections 4.2 to 4.7 is that evolution which results in minimum total cost in the 1980-94 period, subject to certain constraints such as acceptable service throughout the network, acceptable network survivability, limited available spectrum, etc. Strictly speaking, the network should have minimum present value of total incurred costs, taking into account installation of new equipment and maintenance of existing equipment in the 1980-94 interval. As discussed in section 4.1, total annual costs were used in synthesizing the network evolutions, rather than network present value. Although not strictly equivalent, minimization of either network annual costs or network present value results in the same network evolution, if network compatibility is taken into account when annual costs are used.

Search for a network to meet all requirements at minimum total annual cost leads directly to the use of marginal costs of both satellite system additions and terrestrial system additions. (See section 3.3.2 for a more detailed discussion of this point.)

4.8.2 AN ALTERNATIVE: AVERAGE OF FULLY-ALLOCATED COSTING

An alternative to the above marginal costing approach is to use some form of average or fully-allocated costing. An example of such an approach is the current rate structure used by Telesat Canada; they charge $3 million per transponder per year to each of their customers. (There is a slight variation in the rate charged, depending on the amount of ground equipment used in the customer's system.) This $3 million figure is a rate, rather than a cost, in that it also includes corporate profit, corporate tax, municipal taxes, etc., so is not directly comparable to estimated satellite costs. However, it is a cost so far as the TCTS companies and CNCP are concerned and is indicative of the average or "everybody-pays-the-same" approach. Furthermore the customers who own trans-Canada facilities, TCTS and CNCP mainly, compare this rate with their own marginal costs.

Let us compare the annual space cost of a satellite system when average costing is used, and when marginal costing is used. (The "space cost" is the cost of the satellite system except for the costs of the ground stations which carry customers' traffic.) Consider first the total annual cost of the space portion of a satellite system as a function of system capacity. Capacity is of course dependent on the use made of the satellite and the type of modulation used; in this example let us suppose that the satellite is used for voice transmission and that 4 phase PSK with SPEC is used. This system has a capacity of about 900 voice circuits through each 6.5 watt 36 MHz transponder. The annual cost of systems of this type as a function of system capacity, i.e. as a function of the number of operational transponders, is shown in Fig. 4.19.

If average costing is used to determine the cost per voice circuit through the satellite, the cost is the slope of the line from the origin to the point of interest in Fig. 4.19. These costs are $1,350 when a satellite with eight transponders is used, $1,060 when a 12 transponder satellite is used, $700 when a 24 transponder satellite is used, and $450 when a dual satellite system with 24 transponders on each satellite is used.

Now consider marginal costs in this example. Suppose that twelve satellite transponders are required for northern services and for southern television distribution, and that a satellite will be used for these services at a total cost of $11.6 million per year for the space portion of the satellite system, (see section 4.2). In considering whether a larger 24 channel satellite should be used to carry 11,000 voice circuits as well as the television and northern traffic, the marginal cost to carry these voice circuits is about $340, less than half the $700 average cost figure. If an extra 32,000 voice circuits are considered, as was the case when synthesizing the network to meet the maximum 1985 forecast, the marginal cost per voice circuit is $250, slightly more than half the $450 average cost figure. Thus in this example, which is very typical of the satellite options for the Canadian network, the marginal cost per voice circuit for voice traffic is about half the average cost for the same satellite.

4.8.3 EFFECT OF THE LARGE DIFFERENTIAL BETWEEN AVERAGE COSTS AND MARGINAL COSTS

When marginal costing of the satellite system is used, to determine a minimum-total-cost network, a large amount of voice traffic is routed through the satellite system. (See sections 4.4 to 4.7). However, when average costing is used to determine

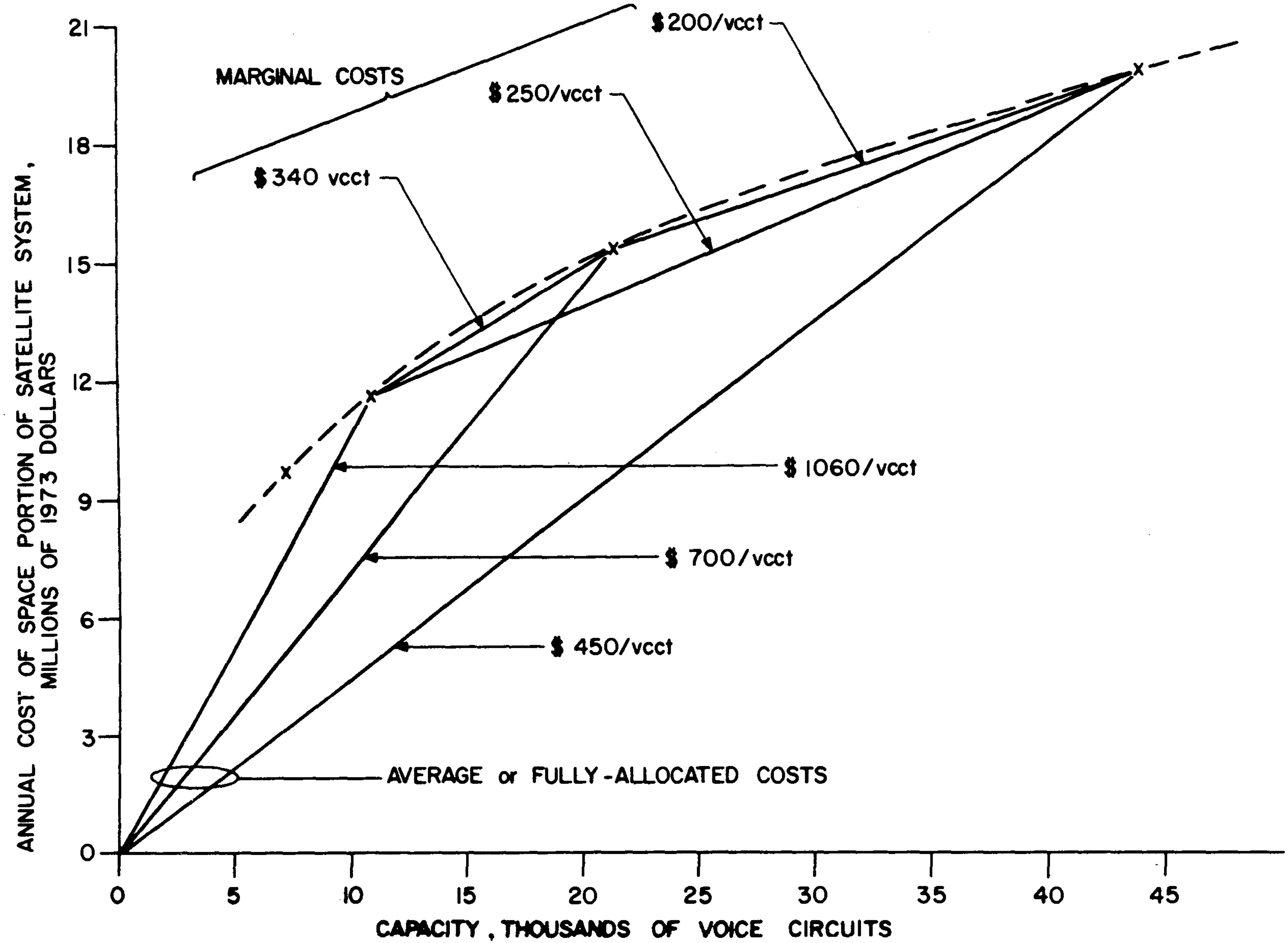


Figure 4.19: Example of Comparison of Marginal and Average Costs

the cost of routing voice traffic through the satellite the results are quite different. No significant amounts of southern voice traffic are routed through the satellite system until the existing terrestrial systems, including the 8 GHz digital add-on system, are saturated.

The reason for this difference can be seen by considering an example. Let us consider the alternatives available to route a block of traffic, say 1800 circuits, between Edmonton and Toronto in 1985. The marginal cost to route this traffic terrestrially through the 8 GHz digital radio system is estimated to be $840 per year per voice circuit. The combined marginal cost of both the space portion and ground portion of the satellite system is about $600, a 30% cost reduction. However, the total cost of a voice circuit through the satellite system is about $990 if average costing is used. This is 18% greater than the terrestrial cost. The result, of course, is that the traffic would be routed terrestrially if average satellite costs were used. The same would apply to traffic between Winnipeg and Montreal, Halifax and Toronto, etc. Because this traffic is lost to the satellite system, a 24 transponder satellite (or two 12 transponder satellites) cannot be filled, and so the average cost increases even further. The end result of this "snowball" effect, which increased the satellite voice traffic when marginal costing was used, is that almost no voice traffic is routed through the satellite.

In general, if average costing of the satellite system were used, TCTS traffic and CNCP traffic would be routed terrestrially until their respective terrestrial systems were saturated. The preferred forecast of voice circuit requirements on the TCTS digital network in 1990 is shown in Fig. 4.20. (In determining the requirements shown in Fig. 4.20 it was assumed that all new TCTS requirements after 1980 would be met by the digital terrestrial system.) The ultimate capacity of an 8 GHz system is about 13,000 voice circuits without source encoding, and 26,000 voice circuits if a coding technique such as SPEC is used. With two parallel systems, as shown in Fig. 4.20, these capacities are doubled. Thus it is evident that, if the preferred forecast is correct, the 8 GHz digital radio system could carry all TCTS voice traffic growth until the 1990's. Similarly, the 6 GHz analog radio system of CNCP can carry all expected CNCP traffic until the 1990's, with possibly the addition of a 6 GHz link directly from Toronto to Montreal.

Thus, if an average or fully-allocated costing procedure is used to determine the cost of a voice circuit through the satellite system, it is very unlikely that the satellite will carry significant voice traffic in southern Canada until the 1990's. In that event, it is likely that an Anik-like satellite

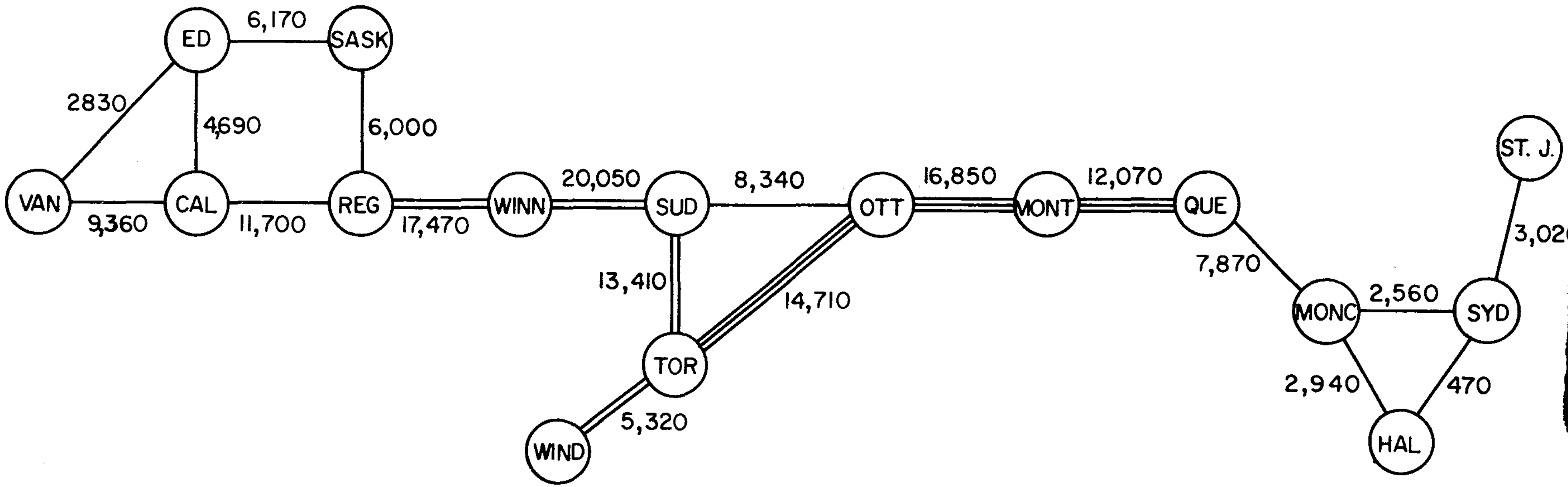


Figure 4.20

Preferred Forecast of Voice Circuit Requirements
Through TCTS Digital Network in 1990
With No Voice Traffic by Satellite

with in-orbit backup would be used in the 1980-87 period, and an RCA-type satellite with an in-orbit backup, or a dual Anik system with in-orbit bakcup, in the 1987-94 period.

Under maximum traffic growth conditions, an RCA-type satellite or a dual Anik-like satellite system would be required in the 1980-87 period, and a dual hybrid satellite system with 12/14 GHz spot beams for high capacity voice transmission in 1987-94. Such a system would be used because the terrestrial systems would saturate in the mid to late 1980's, and a satellite system would be less costly than a new stand-alone trans-Canada terrestrial system.

Under minimum or linear traffic growth conditions, an Anik satellite would be sufficient until the mid 1980's.

The above network evolutions are not, of course, minimum-cost networks. The present value of the additional network costs under expected (preferred) traffic growth conditions are $8 million to $14 million, as shown in Fig. 4.21. The reason for including an average-cost solution in this study is that it is representative of the current situation. The implications of this are discussed below in chapter 5.

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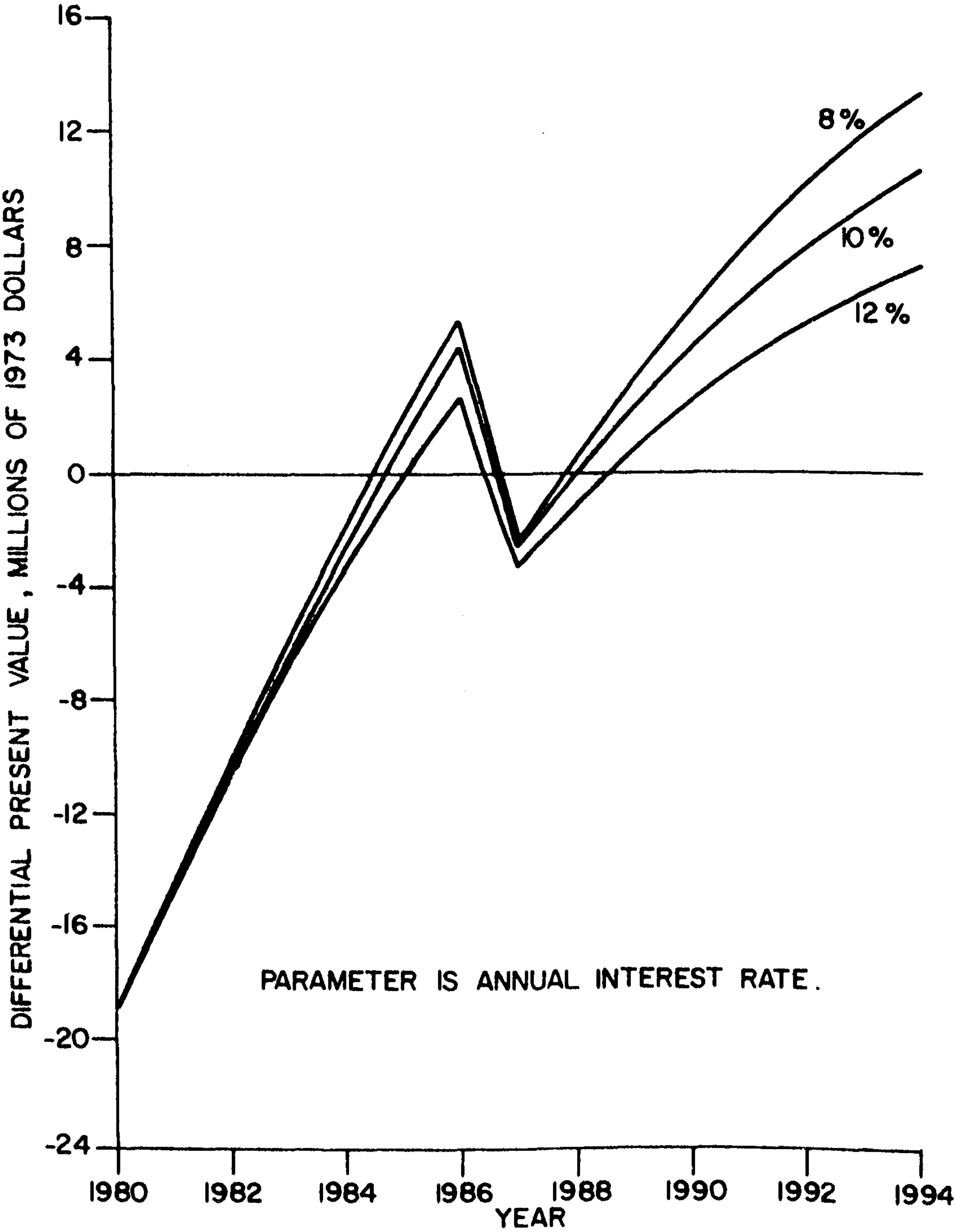

Figure 4.21

Cash - Flow of
Additional National Expenditure
Resulting from a Fully-Allocated-Costing Situation

[redacted]

CHAPTER 5

SUMMARY OF THE RESULTS AND THE EFFECT OF INSTITUTIONAL ARRANGEMENTS

5.1 THE EFFECT OF INSTITUTIONAL ARRANGEMENTS

The major results of chapter 4 were determined on the basis of minimum total cost to meet all long-distance requirements in both northern and southern Canada. This is the point of view that might be taken by a hypothetical, single carrier operating both terrestrial and satellite facilities and serving all needs. (Actually we also assumed a second terrestrial carrier, CN/CP, carrying 16% of message traffic but this is a sufficiently small amount, 1-2 years total network growth, that its effect on the overall results is not significant.) Such a carrier might be expected to make cost-effective use of both satellite and terrestrial facilities without any a priori bias in either direction. (From the point of view of the consumer it is also clear that rates can never be lower than the lowest rate which offers a reasonable rate of return on a minimum cost network.)

This hypothetical situation is clearly far from representing the status quo in Canada and the purpose of this chapter is to discuss some of the implications of current relationships between the carriers.

At the present time TCTS has many reasons for being reluctant to use satellites:

i) it has excess installed capacity in its two 4 GHz microwave systems and this situation may be aggravated as television distribution is tranferred to the satellite system.

ii) the prairie carriers, in particular, benefit from revenues from traffic which passes through their territories but is neither originated nor terminated there.

iii) some switching machines require modification to cope with the much larger delay in a satellite circuit.

iv) neither the satellite nor the ground stations are included in the rate base of the member companies.

v) Telesat charges a leasing rate which:
- is essentially the same no matter what the service.
- is based on the current satellite size.
- includes corporate profits.
- is currently about 3 times the marginal cost to TCTS of adding the same capacity to its microwave systems.

By the early 1980's, the start of our study time-frame,:

- reason (i) will have disappeared because new traffic growth will have absorbed the current slack capacity.

- the introduction of new switching machines, which will occur anyway, will offer the opportunity to avoid the problems of reason (iii) (especially if common channel inter-switch signalling is introduced).

Reasons (ii), (iv) and (v) will remain unless some modification to current institutional arrangements can be implemented. Thus, if the status quo persists, It would be advantageous for CBC, CTV, Global TV, etc, to use the satellite system for nationwide television distribution, but both TCTS and CNCP would likely expand their present systems, including the TCTS 8 GHz overbuild system, to saturation before leasing capacity from Telesat. At that time it would be cost-effective for both TCTS and CNCP to lease capacity from Telesat rather than build new stand-alone terrestrial systems. It is unlikely that this would happen before the early or mid 1990's.

The result would be a network with lower survivability than would be the case if significant use were made of satellite and the total cost to the collectivity of consumers would be higher. The magnitude of the extra cost, and the nature of the network, is roughly represented by the solution, presented in chapter 4, which was based on average, rather than marginal, costing of satellite capacity.

In contrast, if some mechanism could be found by which TCTS, CNCP, and Telesat (or at least TCTS and Telesat) co-operated in evolving a minimum-total-cost network, the network would evolve in a very different way. A large amount of long-haul voice traffic would be routed through the satellite system until, in the late 1980's, the amount of voice traffic through the satellite system would be limited by the survivability requirements of the overall network. The mechanism would have to include ways of resolving problems (ii), (iv) and (v).

In neither the "continuation-of-the-status-quo" situation nor the "co-operative-minimum-total-cost" situation is it likely that a new trans-Canada, stand-alone terrestrial system will be built by either TCTS or CNCP until present terrestrial systems are fully utilized and traffic through the satellite system is limited by network survivability considerations. This is not likely to happen before the turn of the century.

5.2 TERRESTRIAL NETWORK EVOLUTION

It is expected that four transmission media will be used for long-haul terrestrial transmission in the 1970's and 1980's. These are:

i) the TCTS 4 GHz analog radio system,

ii) the CNCP 6 GHz analog radio system,

iii) the TCTS 8 GHz digital overbuild on the 4 GHz analog radio system.

iv) the TCTS LD-4 digital coaxial cable system.

The 4 GHz analog radio system is not likely to be expanded significantly in the next decade, although its present installed capacity is much less than its ultimate capacity in most places. A possible exception is in the Toronto-Montreal link, but even here the system capacity could be significantly increased if modern equipment were used. The reasons for this limitation of 4 GHz system growth are firstly, the conversion of the TCTS system to a digital one in the 1980's, and secondly, the transferral of television distribution to the satellite system. One possible way of using the 4 GHz band more efficiently would be to convert it to digital use as the 8 GHz band becomes full and the amount of analog transmission diminishes. In addition a 6 GHz overbuild of at least the inter-provincial 4 GHz route would be possible. Similar overbuilding of the trans-Canada route may not be feasible because of interference with the adjacent CNCP 6 GHz route.

The 6 GHz analog radio system seems able to meet CNCP's requirements throughout the 1980's, with possibly a new route addition between Toronto and Montreal. This forecast is made on the assumption that CNCP will continue to handle about 16% of the long-haul voice traffic, and that television programs will be distributed by satellite.

The LD-4 digital coaxial cable system is being installed between Toronto and Montreal. It may be extended from Toronto to London and from Montreal to Quebec City, but it may not be used elsewhere in the Canadian network except to alleviate frequency congestion problems in metropolitan junctions. The reason for this is that its costs seem at present to be higher than the expected costs of both the 8 GHz digital overbuild system and the high-capacity stand-alone 12 GHz digital radio system. This situation may change, however, if improved cable laying procedures can be developed at lower cost.

The 8 GHz digital radio overbuild system is expected to carry almost all the expansion of TCTS terrestrial system in the 1980's. It will expand to full capacity quite quickly under status-quo institutional arrangements, and more slowly if a mechanism can be developed between the carriers to evolve a minimum-cost network.

When the 8 GHz digital radio becomes filled it is likely that one or more of the following will take place:

i) a 6 GHz digital radio system will be added to the 4 GHz system in much the same way that the 8 GHz digital radio system was added;

ii) the 4 GHz analog radio system will be converted to a digital system, perhaps first by using the lower portion of the 4 GHz band between 3.5 GHz and 3.7 GHz;

iii) an independent 12 GHz high-capacity digital radio system or an optic-fibre system will be constructed.

Option (iii) is expected to be the most costly and therefore last to be implemented. Even under the present institutional arrangements it would be less expensive for TCTS to use a high-capacity satellite system than to build a third independent trans-Canada system.

5.3 SATELLITE SYSTEM EVOLUTION

Under present institutional arrangements a satellite system is required to carry thin-route voice traffic in northern Canada, national and regional television distribution in northern Canada, and national television distribution in southern Canada. An augmented Anik-type satellite would meet this requirement in the 1980-87 period, and an RCA-type satellite would suffice in the later 1987-94 time-frame. Both systems operate at 4/6 GHz and use Canada-wide antenna beams on the satellite.

If the institutional arrangements could be changed between the common carriers, so that the network could evolve in a minimum-cost manner, a larger satellite system would be required. In such a system a large amount of voice traffic would be routed through the satellite. A dual Anik-like satellite system would be the most cost effective in the 1980-87 interval, and a dual RCA-type satellite system in 1987-1994. Satellite ground stations in southern Canada should be augmented such that they can use two or perhaps three satellites simultaneously. This could be done either by installing a second set of parabolic antennas at each ground station, or perhaps a single toroidal antenna in place of the existing parabolic antenna.

The dual RCA-type satellite system would have the capacity to meet the expected northern requirements, nationwide television distribution requirements, and carry up to 30,000 voice circuits. The amount of voice traffic routed through the satellite must ultimately be limited by the network survivability requirements.

If the satellite system could carry more traffic than the above in a cost-effective survivable network, then 12/14 GHz and spot beams should be used on the satellite for voice transmission. It is not expected that such a system will be required until the mid 1990's, but it would be required in the 1987-94 time-frame under maximum traffic growth conditions.

5.4 COST-EFFECTIVE USE OF SATELLITE FREQUENCY BANDS

The relative advantages of the 4/6 GHz band and the 12/14 GHz band were discussed in considerable detail in section 4.7. It was shown that:

i) The 4/6 GHz band should continue to be used for those services which require a Canada-wide coverage and moderate satellite EIRP. These services include nationwide television distribution, northern regional television distribution, thin-route voice transmission from established northern communities, and medium-capacity voice transmission using TDMA over links such as Edmonton to Halifax.

ii) The 12/14 GHz band should be used for high-capacity voice transmission as the 4/6 GHz band becomes saturated. It is expected that in the 1990's, or perhaps in the late 1980's, a hybrid satellite system will be used which includes a 12/14 GHz system with 0.5° to 1.5° spot beams and one to five watt transponders. Such a system would have a capacity in the 100,000 voice circuit range.

[redacted]

iii) Uses such as regional television distribution, in which the coverage area of a specific signal is 1° to 3° and one to two hundred ground stations are included in the overall system, can be designed equally well at 4/6 GHz and at 12/14 GHz. The determining factors in choosing the frequency band seem to be whether the technology is developed when the system is required, and whether the frequency band is available.

These results were obtained in considering the evolution of the satellite/terrestrial network for voice transmission between established communities and the distribution of network-quality television.

There are, of course, other communication services in Canada which will probably be met with satellite systems. These include:

i) Simplex or perhaps duplex distribution of audio and video signals to thousands of fixed ground terminals to provide educational and medical services to remote communities, and for the direct broadcast of CBC television and radio programs;

ii) Communication between mobile terminals, and data collection from isolated terminals.

These requirements were not included in the DLDCNS, because the type of satellite system required is quite different from that required of the systems considered in the DLDCNS. For requirement (i) above it is cost-effective to use a satellite with high EIRP (such as CTS) if thousands of ground terminals are used. For requirement (ii) the ground terminals must again be small, light, and inexpensive. Satellite systems for requirement (i) should operate at 2.5 GHz or 12/14 GHz, and satellites for requirement (ii) should operate at 300 MHz, 1.5 GHz, or 2.5 GHz.

In choosing the frequency band for any of these satellite systems, the effect of that choice on the design of other systems, and the cost of the <u>overall</u> network, should be considered. Because of the attractiveness of the 12/14 GHz band for requirement (i), it would seem logical to design any network regional television distribution system at 4/6 GHz where there is ample spectrum and very little cost penalty of choosing 4/6 rather than 12/14. Further, if a significant amount of the 12/14 GHz band is used for requirement (i), the 18/30 GHz band should be considered for high-capacity voice transmission. Such a system would not be required before the 1990's. By that time it is very likely that the necessary technology will have been developed for a high-capacity U.S. domestic system.

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APPENDIX A

FORECASTS OF LONG-DISTANCE TRANSMISSION CAPACITY REQUIREMENTS

A.1 INTRODUCTION

This appendix deals with the forecasts of long-distance transmission capacity requirements which were made as part of the study and which were the basis of the system syntheses discussed in the report. The forecasts cover the requirements between the hatched nodes in Fig. A.1 which represent major population centres and collection centres for the traffic from large populated areas. They also cover those northern areas of Canada which can only be served economically by satellite.

Forecasts are divided into three classes of traffic: public switched telephone, leased lines, data and other message traffic constitutes one class, television channels a second, and thin-route voice requirements in established Arctic communities constitute the third class. For each class of traffic, forecasts have been made for the years 1980, 1985 and 1990. For each year three forecasts: maximum, preferred and minimum, are made. The terms maximum and minimum are not, of course, absolute, they imply maximum and minimum likely values. The preferred forecast lies between these two extremes and is called "preferred" for this reason. In the forecasts of voice circuit requirements, "maximum" and "minimum" corresponds to the geometric mean of these two. In the television forecasts, where we had even less data than for voice circuits, the forecasts are based on more subjective judgement.

Since the object of the study is to determine the most effective way of meeting the requirements, they are stated in terms of end-to-end capacity. In other words, if we forecast that a certain number of voice circuits is required between Ottawa and Montreal, we mean the capacity required to connect the areas surrounding Ottawa and Montreal together, we do not include through traffic, say Quebec to Toronto. The latter requirement is stated as another end-to-end requirement.

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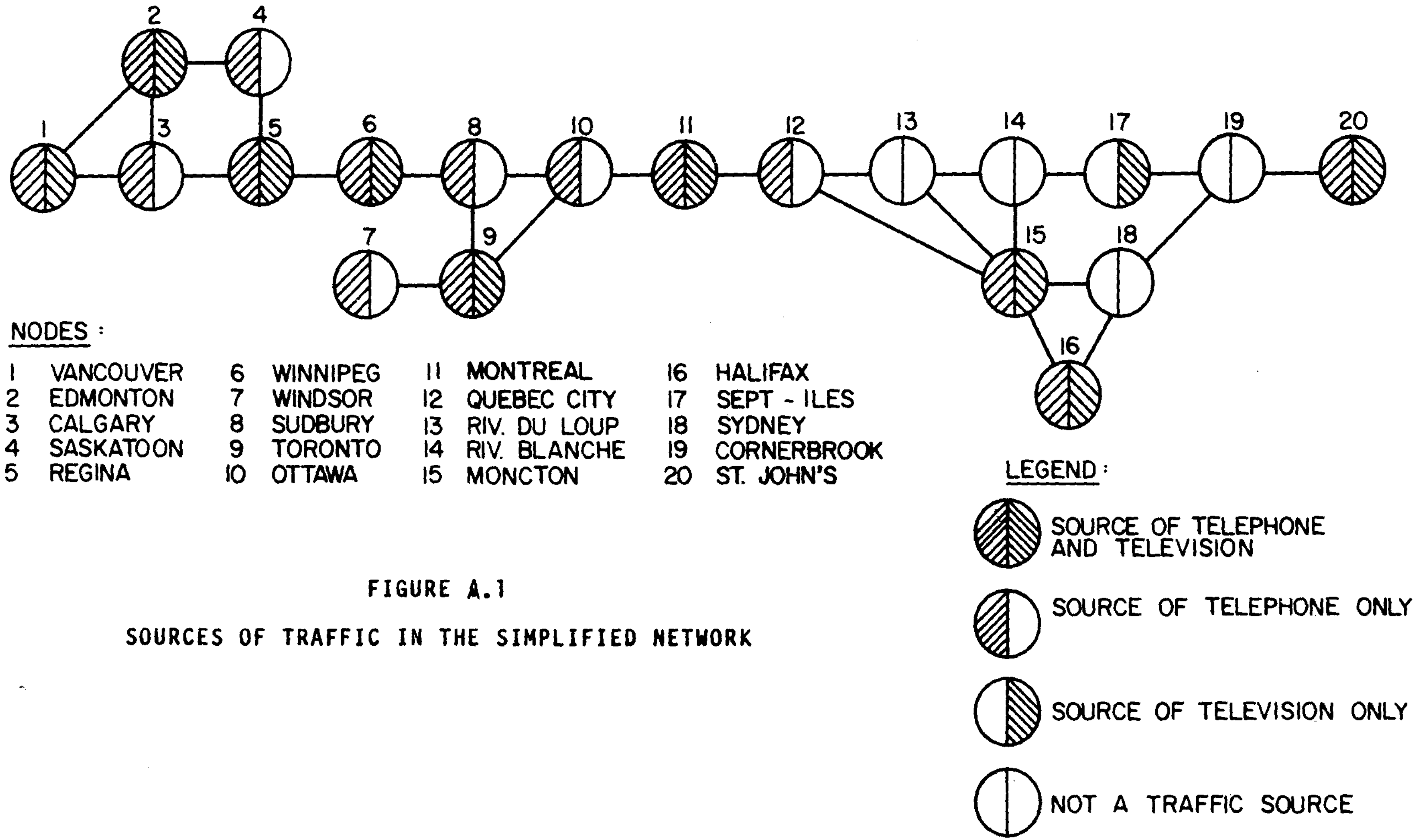

FIGURE A.1

SOURCES OF TRAFFIC IN THE SIMPLIFIED NETWORK

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A.2 VOICE CIRCUIT REQUIREMENTS

Forecasting of voice circuit requirements was carried out in two stages. First of all forecasts were produced on an inter-regional basis with the nodes aggregated as shown in Fig. A.2. This stage allowed us to utilize the results of the DOC Inter-regional Working Group* as one of our inputs. Subsequently the forecast inter-regional requirements were split up between the individual nodes within a province and intra-regional forecasts were added.

A.2.1 INTER-REGIONAL REQUIREMENTS

Certain geographical gaps were present in the data available to us, as for instance, is the case with the 1973 requirements shown in Table A.1. These gaps were filled by gravity modelling. The gravity model hypothesizes that the traffic T between two point populations P_1 and P_2 situated a distance R apart is

$$T = k\frac{P_1P_2}{R^n}$$

where k and n are appropriate fitted constraints. This can be rewritten as

$$\ell n \frac{T}{P_1P_2} = \ell n(k) - n\ \ell n(R)$$

The coefficients in this functional relationship were determined by least-squares fits to the data that was available to us. The result was a complete table of inter-regional requirements, as shown in Table A.2.

Extrapolation in time was achieved by least-squares curve fitting to the available historical data. This data proved to be too limited to determine whether exponential or linear growth patterns would provide the best forecasts. Accordingly we used

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* DOC Internal Document - Report of the Inter-regional Working Group, December 1972.

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A SIMPLIFIED REPRESENTATION OF THE CANADIAN TELECOMMUNICATIONS NETWORKS

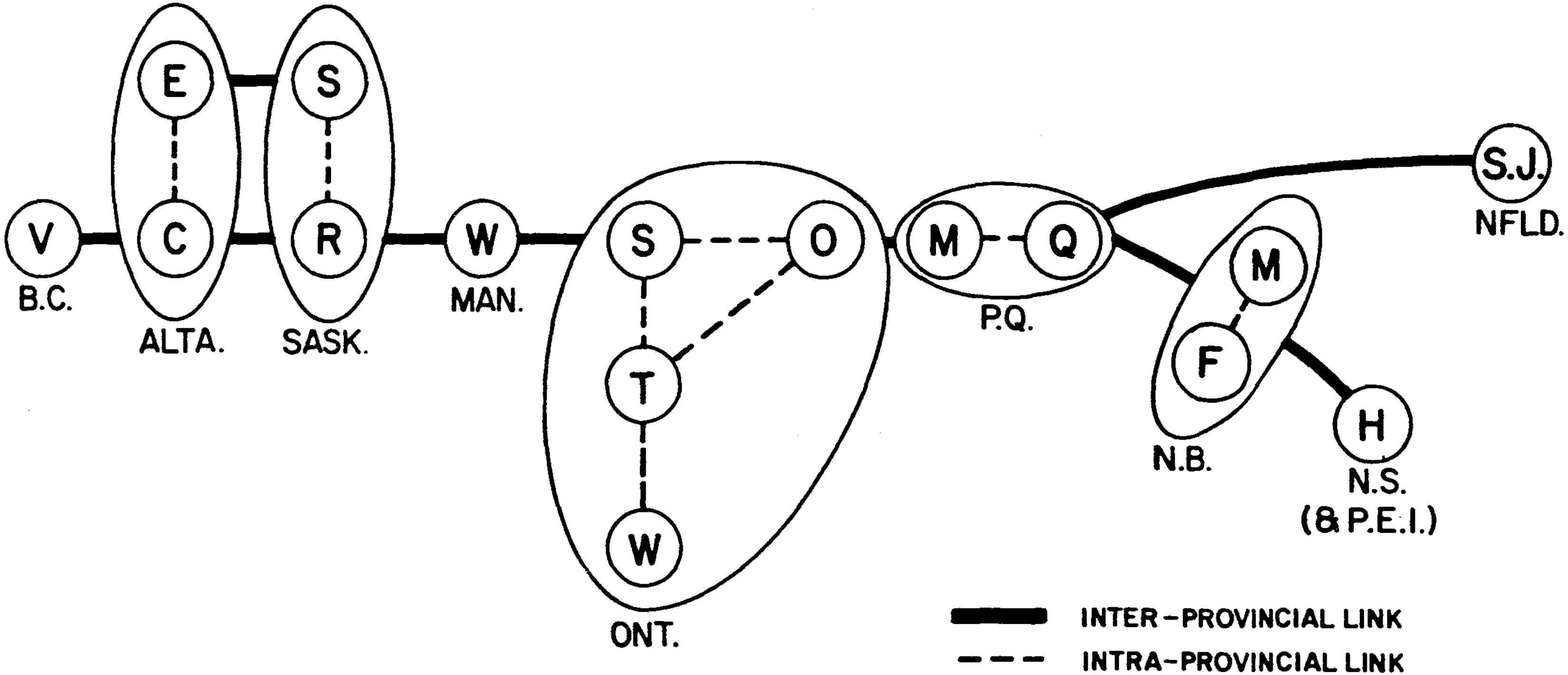

Figure A.2

Aggregation of Network Nodes Within a Province

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Table A.1

Inter-Regional Working Group
Forecast of Voice Circuit
Requirements for 1973

	ALTA	SASK	MAN	ONT	P.Q.	N.B.	N.S. P.E.I.	NFLD
B.C	798	188	175	360	186	0	12	0
ALTA		469	328	394	133	0	0	0
SASK			435	185	69	0	7	0
MAN				710	185	6	0	0
ONT					4,267	174	168	40
P.Q.						607	221	171
N.B.							471	20
N.S. P.E.I.								150

(END TO END REQUIREMENTS)

KEY: MAXIMUM / PREFERRED / MINIMUM

[redacted]

[redacted]

Table A.2

Estimate of Inter-Regional Voice Circuit Requirements for 1973

	ALTA	SASK	MAN	ONT	P.Q.	N.B.	N.S. P.E.I.	NFLD
B.C	798	188	175	360	186	26	12	20
ALTA		469	328	394	133	22	30	16
SASK			435	185	69	13	7	10
MAN				710	185	6	26	13
ONT					4,267	174	168	40
P.Q.						607	221	171
N.B.							471	20
N.S. P.E.I.								150

(END TO END REQUIREMENTS)

KEY: MAXIMUM PREFERRED MINIMUM

[redacted]

both. On the basis that we do not believe that traffic is likely to grow more rapidly than exponentially or more slowly than linearly we took these two trends as our basic maximum and minimum forecasts. The geometric mean of the two was used as our basic preferred forecast. These basic time trends were modified using any available evidence of regional variations such as population growth statistics and the 1980 forecasts of the inter-regional working group. The latter information is shown in Table A.3.

The methodology mentioned briefly above has been described in DLDCNS interim reports No. 2, 3 and 4. The final inter-regional forecasts for 1980, 1985 and 1990 respectively are shown in Tables A.4, A.5 and A.6.

For those regions (specifically the provinces of Alberta, Saskatchewan, Ontario and Quebec) which include more than one node the inter-regional requirements must be apportioned between the appropriate nodes. This was done using a modified gravity technique in which each total requirement was apportioned between each pair of corresponding nodes according to the product of the populations of the nodes. The populations to be used were determined by multiplying the percentages of metropolitan populations, as shown in Table A.7, by factors which were estimated to give the population of the "telecommunications catchment area" of each node as shown in Table A.8.

A.2.2 INTRA-REGIONAL REQUIREMENTS

For the purpose of estimating and forecasting the intra-regional requirements between nodes within each region we had even less available data than for the inter-regional case. 1973 estimates were made by assuming a proportional relationship between inter and intra-regional requirements, using the modified gravity technique previously described and calibrating against the minimal available data. The method was described in DLDCNS interim report No. 7. Clearly a method such as this cannot take any account of regional variations, such as the relative level and type of industrialization, which are bound to have an effect on requirements. In fact our confidence level in the intra-regional forecasts is low. Fortunately it is not likely that satellite facilities compete with terrestrial ones for these distances so that the inaccuracy here should have little effect on the results of the study.

[redacted]

Table A.3

Inter-Regional Working Group
Forecast of Voice Circuit
Requirements for 1980

	ALTA	SASK	MAN	ONT	P.Q.	N.B.	N.S. P.E.I.	NFLD
B.C	1,944	605	510	1,563	547	4	0	0
ALTA		929	861	1,061	345	0	0	0
SASK			1,039	458	254	12	15	0
MAN				1,749	603	14	0	0
ONT					9,448	279	365	76
P.Q.						1,119	435	646
N.B.							966	58
N.S. P.E.I.								298

(END TO END REQUIREMENTS)

KEY: MAXIMUM / PREFERRED / MINIMUM

[redacted]

[redacted]

Table A.4

Forecast of Inter-Regional Voice Circuit Requirements for 1980

	ALTA	SASK	MAN	ONT	P.Q.	N.B.	N.S. P.E.I.	NFLD
B.C	2,839 2,107 1,564	774 530 363	768 498 323	2,266 1,260 701	665 470 332	119 72 43	68 39 22	99 58 34
ALTA		1,430 1,098 843	1,183 820 568	2,826 1,481 776	602 387 249	93 57 35	123 75 46	75 45 27
SASK			1,250 949 720	815 526 340	204 156 118	50 32 20	33 19 11	40 24 14
MAN				3,602 2,191 1,333	502 394 309	25 15 9	89 57 37	52 32 20
ONT					10,838 8,707 6,995	774 497 319	743 480 310	275 146 78
P.Q.						1,610 1,276 1,011	664 502 379	969 556 319
N.B.							982 843 724	67 48 34
N.S. P.E.I.								451 335 248

(END TO END REQUIREMENTS)

KEY: MAXIMUM / PREFERRED / MINIMUM

[redacted]

Table A.5

Forecast of Inter-Regional Voice Circuit
Requirements for 1985

	ALTA	SASK	MAN	ONT	P.Q.	N.B.	N.S. P.E.I.	NFLD
B.C	7,108 4,010 2,262	2,118 1,032 502	2,231 984 434	8,434 2,823 944	1,653 850 437	353 140 56	236 83 29	314 119 45
ALTA		3,124 1,874 1,124	2,957 1,472 733	11,546 3,481 1,049	1,772 767 331	254 105 44	338 138 56	223 87 34
SASK			2,622 1,540 905	2,354 1,030 451	445 262 154	130 56 24	98 37 14	112 45 18
MAN				11,495 4,521 1,778	1,025 639 399	69 28 11	217 97 43	139 58 24
ONT					21,094 13,735 8,943	2,247 976 423	2,150 941 412	1,093 340 105
P.Q.						3,232 2,050 1,300	1,459 848 493	3,345 1,192 424
N.B.							1,647 1,211 890	154 83 43
N.S. P.E.I.								981 553 312

(END TO END REQUIREMENTS)

KEY: MAXIMUM / PREFERRED / MINIMUM

[redacted]

Table A.6

Forecast of Inter-Regional Voice Circuit Requirements for 1990

	ALTA	SASK	MAN	ONT	P.Q.	N.B.	N.S. P.E.I.	NFLD
B.C	17,798 7,431 3,102	5,765 1,941 653	6,498 1,892 551	31,389 6,108 1,188	4,108 1,493 542	1,041 266 68	820 172 36	995 237 56
ALTA		6,736 3,078 1,407	7,346 2,554 888	47,173 7,900 1,323	5,214 1,470 414	690 187 51	920 244 65	654 163 40
SASK			5,435 2,408 1,067	6,796 1,954 562	969 429 190	331 95 27	289 68 16	311 81 21
MAN				36,674 9,029 2,223	2,093 1,011 488	189 50 13	526 158 47	368 101 28
ONT					41,054 21,146 10,892	6,527 1,856 527	6,220 1,788 514	4,340 760 133
P.Q.						6,488 3,211 1,590	3,204 1,394 607	11,548 2,475 530
N.B.							2,745 1,689 1,039	371 138 51
N.S. P.E.I.								2,123 886 370

(END TO END REQUIREMENTS)

KEY: MAXIMUM / PREFERRED / MINIMUM

[redacted]

Table A.7

Projected Populations (in Millions)
For Specified Census Metropolitan
Areas (i.e. Major Cities)

CITY	YEAR				
	1966 (Census)	1973	1980	1985	1990
EDMONTON	0.401	0.500	0.612	0.703	0.796
CALGARY	0.331	0.409	0.497	0.569	0.643
SASKATOON	0.116	0.150	0.188	0.218	0.250
REGINA	0.131	0.159	0.190	0.215	0.241
SUDBURY[1]	0.085	0.092	0.099	0.105	0.110
OTTAWA	0.495	0.590	0.695	0.776	0.859
TORONTO	2.158	2.682	3.264	3.714	4.178
WINDSOR	0.212	0.237	0.262	0.283	0.303
MONTREAL	2.437	2.923	3.448	3.847	4.252
QUEBEC	0.413	0.497	0.588	0.657	0.726

Note: 1. Assuming growth rate of Winnipeg.

Source: Systems Research Group, Canada Population Projections to the 2000, S.R.G., Toronto, 1970; Figure 5

Table A.8

Subjectively Estimated Conversion Factors to Relate Urban Populations of "Catchment Areas" to Populations of Metropolitan Areas

CITY	CONVERSION FACTOR
EDMONTON	x 1.1
CALGARY	x 1.2
SASKATOON	x 1.3
REGINA	x 1.4
SUDBURY	x 2.0
OTTAWA	x 1.3
TORONTO	x 1.5
WINDSOR	x 2.0
MONTREAL	x 1.0
QUEBEC	x 1.0

A.2.3 THE COMPLETE FORECAST

The result of combining the output of the two processes described above is the complete set of forecasts between each pair of nodes. The forecasts are shown in Tables A.9 - A.18.

A.3 TELEVISION CHANNEL REQUIREMENTS

In addition to being a different class of traffic, television signal distribution requires a different type of facility. In broadcasting, the main requirement is for a simplex, wideband channel connecting a single source to multiple sinks. In addition there are requirements for simplex channels for the purpose of feeding programme material to the production centre. CATV companies are beginning to bring programmes to their distribution centre by means of dedicated transmission facilities in addition to their normal off-air pick-ups. There will be many new uses for television channels for educational (ETV) and other purposes, most of which are not now in operation. We have classed all these latter requirements under the designation Other TV but our forecasts of them represent little more than guess-work since virtually no information base is available. In fact, with the exception of CBC, we were able to obtain very little information on any aspect of future demand for long-distance television transmission. To a considerable extent such information cannot be expected since private corporations are not in the habit of revealing their long-term plans and many of the possible sources of such requirements, such as educational services and interconnection of cable TV companies are at present almost non-existent. Accordingly we have prepared our own forecasts using a rather opaque crystal ball. We wish to stress, therefore, that the forecasts in this Appendix are our own and do not represent expressed plans of any of the television corporations. However, the CBC requirements are based on the joint DOC/CBC Broadcasting Satellite Study (final report February 13, 1974) and discussions with its authors.

The forecasts are presented in Tables A.19 to A.21 which must be read in conjunction with the explanatory notes which follow.

A.3.1 EXPLANATORY NOTES FOR TABLES A.19 TO A.21

Each entry in the first column is the title of a particular service which is described under the same title below. Any entry opposite this in another column indicates that service is included in the corresponding forecast. If the entry is "N"

Table A.9

1973 Estimate of Inter-Nodal Voice Circuit Requirements

	CAL	EDM	SASK	REG	WINN	SUD	TOR	WIND	OTT	MTL	QUE	MONC	HAL	ST JHN
VAN	358	437	89	96	174	17	240	42	53	156	27	18	18	20
CAL		455	100	109	147	8	117	20	26	49	8	10	10	7
EDM			123	133	179	10	144	25	31	61	10	13	13	9
SASK				249	207	3	58	10	12	27	4	4	4	5
REG					225	4	63	10	13	29	4	4	4	5
WINN						35	475	84	106	155	27	15	15	12
SUD							153	10	21	180	31	8	8	2
TOR								395	642	2428	428	114	114	27
WIND									37	434	76	20	20	5
OTT										543	95	25	25	6
MTL											919	350	350	145
QUE												61	61	26
MONC													621	85
HAL														85

Table A.10

1980 Maximum Forecast of Internodal
Voice Circuit Requirements

	CAL	EDM	SASK	REG	WINN	SUD	TOR	WIND	OTT	MTL	QUE	MONC	HAL	ST JHN
VAN	1285	1570	370	400	771	112	1517	271	339	564	99	92	92	99
CAL		2010	305	331	531	63	851	152	190	229	40	47	47	33
EDM			373	404	649	77	1040	186	232	280	49	58	58	41
SASK				886	594	19	261	46	58	82	14	19	19	19
REG					644	20	283	50	63	89	15	20	20	21
WINN						179	2412	431	539	426	74	56	56	51
SUD							541	43	83	460	80	37	37	14
TOR								1430	2451	6171	1088	507	507	184
WIND									163	1104	194	90	90	33
OTT										1381	243	113	113	41
MTL											2599	967	967	823
QUE												170	170	145
MONC													820	257
HAL														257

Table A.11

1980 Preferred Forecast of Internodal
Voice Circuit Requirements

	CAL	EDM	SASK	REG	WINN	SUD	TOR	WIND	OTT	MTL	QUE	MONC	HAL	ST JHN
VAN	976	1194	256	277	501	62	843	150	188	398	69	54	54	58
CAL		1335	236	256	366	32	445	79	99	147	25	28	28	20
EDM			289	313	448	40	545	97	121	180	31	35	35	24
SASK				647	449	12	168	29	37	62	10	11	11	11
REG					487	13	182	32	40	68	11	12	12	12
WINN						109	1467	262	328	334	58	34	34	31
SUD							366	26	53	369	64	18	18	7
TOR								972	1679	4957	874	259	259	97
WIND									97	887	156	46	46	17
OTT										1109	195	57	57	22
MTL											2007	755	755	472
QUE												132	132	83
MONC													927	189
HAL														189

Table A.12

1980 Minimum Forecast of Internodal Voice Circuit Requirements

	CAL	EDM	SASK	REG	WINN	SUD	TOR	WIND	OTT	MTL	QUE	MONC	HAL	ST JHN
VAN	742	907	177	192	325	34	468	83	104	281	49	31	31	34
CAL		887	183	198	253	16	233	41	51	94	16	17	17	12
EDM			224	242	309	20	285	50	63	115	19	21	21	14
SASK				473	339	7	108	19	23	47	7	6	6	7
REG					368	8	117	20	26	51	8	7	7	7
WINN						66	891	159	199	262	45	21	21	19
SUD							247	16	34	296	51	9	9	4
TOR								660	1150	3982	702	132	132	52
WIND									58	712	125	23	23	9
OTT										891	156	29	29	12
MTL											1550	590	590	270
QUE												103	103	48
MONC													1048	138
HAL														138

Table A.13

1985 Maximum Forecast of Internodal
Voice Circuit Requirements

	CAL	EDM	SASK	REG	WINN	SUD	TOR	WIND	OTT	MTL	QUE	MONC	HAL	ST JHN
VAN	3198	3908	1015	1100	2229	421	5649	1011	1264	1403	247	293	293	313
CAL		5808	674	730	1329	259	3480	622	778	677	119	132	132	100
EDM			823	892	1625	316	4253	761	951	827	145	162	162	123
SASK				2185	1258	55	756	135	168	180	31	54	54	53
REG					1362	60	819	146	183	195	34	58	58	58
WINN						574	7700	1378	1723	869	153	141	141	138
SUD							1327	111	212	895	157	109	109	55
TOR								3577	6377	12012	2119	1472	1472	732
WIND									465	2151	379	263	263	131
OTT										2688	474	329	329	164
MTL											5457	1992	1992	2842
QUE												351	351	502
MONC													998	567
HAL														567

Table A.14

1985 Preferred Forecast of Internodal
Voice Circuit Requirements

	CAL	EDM	SASK	REG	WINN	SUD	TOR	WIND	OTT	MTL	QUE	MONC	HAL	ST JHN
VAN	1803	2204	494	535	983	140	1889	338	422	721	126	111	111	119
CAL		2637	404	437	661	77	1048	187	234	292	51	54	54	39
EDM			494	535	809	95	1281	229	286	357	62	66	66	48
SASK				1176	738	24	330	58	73	106	18	21	21	21
REG					800	26	358	63	79	115	19	23	23	23
WINN						225	3028	541	677	542	95	61	61	58
SUD							647	47	96	583	102	34	34	17
TOR								1743	3106	7821	1379	462	462	227
WIND									186	1400	246	82	82	41
OTT										1750	308	103	103	51
MTL											3305	1231	1231	1012
QUE												216	216	179
MONC													1162	317
HAL														317

Table A.15

1985 Minimum Forecast of Internodal
Voice Circuit Requirements

	CAL	EDM	SASK	REG	WINN	SUD	TOR	WIND	OTT	MTL	QUE	MONC	HAL	ST JHN
VAN	1017	1243	240	260	433	46	631	112	141	370	65	42	42	45
CAL		1197	242	262	329	23	315	56	70	126	21	21	21	15
EDM			296	320	402	28	386	68	86	154	26	26	26	19
SASK				633	433	10	144	25	31	62	10	8	8	9
REG					470	11	156	27	34	67	11	9	9	9
WINN						88	1190	212	266	338	59	26	26	24
SUD							315	20	43	379	66	10	10	5
TOR								849	1513	5092	898	145	145	70
WIND									74	911	160	25	25	13
OTT										1139	200	32	32	16
MTL											2001	761	761	360
QUE												133	133	64
MONC													1353	178
HAL														178

Table A.16

1990 Maximum Forecast of Internodal
Voice Circuit Requirements

	CAL	EDM	SASK	REG	WINN	SUD	TOR	WIND	OTT	MTL	QUE	MONC	HAL	ST JHN
VAN	7955	9722	2787	3020	6442	1568	21028	3765	4707	3490	615	921	921	989
CAL		16770	1486	1610	3325	1060	14220	2546	3183	1993	351	366	366	301
EDM			1816	1968	4064	1296	17380	3112	3890	2436	429	447	447	367
SASK				5388	2659	162	2184	390	488	394	69	150	150	147
REG					2881	176	2366	423	529	426	74	162	162	159
WINN						1833	24570	4400	5500	1776	313	355	355	373
SUD							3249	286	541	1744	307	318	318	217
TOR								8945	16593	23378	4125	4268	4268	2905
WIND									1327	4186	738	764	764	520
OTT										5233	923	955	955	650
MTL											11454	4105	4105	9815
QUE												724	724	1732
MONC													1216	1251
HAL														1251

Table A.17

1990 Preferred Forecast of Internodal
Voice Circuit Requirements

	CAL	EDM	SASK	REG	WINN	SUD	TOR	WIND	OTT	MTL	QUE	MONC	HAL	ST JHN
VAN	3205	3917	919	995	1866	304	4089	731	915	1266	223	218	218	233
CAL		5026	669	724	1160	177	2379	425	532	560	98	98	98	74
EDM			817	886	1418	216	2908	520	650	685	120	120	120	91
SASK				2066	1184	46	627	111	140	173	30	39	39	38
REG					1283	50	679	121	151	188	32	43	43	42
WINN						450	6047	1082	1353	858	151	105	105	102
SUD							1115	82	167	898	158	60	60	38
TOR								3046	5578	12041	2124	821	821	507
WIND									345	2156	380	146	146	91
OTT										2695	475	183	183	113
MTL											5299	1956	1956	2101
QUE												344	344	371
MONC													1419	520
HAL														520

Table A.18

1990 Minimum Forecast of Internodal
Voice Circuit Requirements

	CAL	EDM	SASK	REG	WINN	SUD	TOR	WIND	OTT	MTL	QUE	MONC	HAL	ST JHN
VAN	1291	1578	302	328	540	58	794	141	177	459	80	51	51	55
CAL		1506	301	326	404	29	397	70	88	157	27	26	26	18
EDM			368	398	495	35	486	86	108	192	33	32	32	23
SASK				792	527	12	179	31	39	76	13	10	10	10
REG					571	14	194	34	43	83	14	11	11	11
WINN						110	1488	266	332	414	72	30	30	28
SUD							382	23	51	462	81	11	11	7
TOR								1037	1875	6201	1094	157	157	88
WIND									89	1110	195	27	27	16
OTT										1388	244	34	34	20
MTL											2451	932	932	450
QUE												164	164	79
MONC													1657	216
HAL														216

[redacted]

Table A.19

Television Requirements for 1980

SERVICE	MINIMUM FORECAST	PREFERRED FORECAST	MAXIMUM FORECAST
CBC Arctic Regional			
English East	N	N	N
English West	N	N	N
French	N	N	N
CBC National Dist.			
English	N+S	N+S	N+S
French*	S	S	S
CBC National Omnibus		N+S	N+S
CTV Network Dist.*	S	S	S
Global Dist.*	Ont.	Montreal-West	Montreal-West
Other TV*			S

* These entries are a requirement for service in Southern Canada only, all other services in the table require satellite facilities since microwave facilities do not extend to the northern areas which require the service.

[redacted]

[redacted]

Table A.20

Television Requirements for 1985

SERVICE	MINIMUM FORECAST	PREFERRED FORECAST	MAXIMUM FORECAST
CBC Arctic Regional			
English East	N	N	N
English West	N	N	N
French	N	N	N
CBC National Dist.			
English	N+S	N+S	N+S
French*	S	S	S
CBC National Omnibus		N+S	N+S
CBC 2nd National (special signal for regional centres)			
English East			N+S
English West			N+S
French East*			S
French West*			S
CTV Network Dist.*	S	S	S
CTV Return Feed*			S
Global Dist.*	Ont.	Montreal-West	Trans-Canada
Other TV*		S	SX2

* These entries are a requirement for service in Southern Canada only, all other services in the table require satellite facilities since microwave facilities do not extend to the northern areas which require the service.

[redacted]

[redacted]

Table A.21

Television Requirements for 1990

SERVICE	MINIMUM FORECAST	PREFERRED FORECAST	MAXIMUM FORECAST
CBC Arctic Regional			
English East	N	N	N
English West	N	N	N
French	N	N	N
CBC National Dist.			
English	N+S	N+S	N+S
French*	S	S	S
CBC National Omnibus		N+S	N+S
CBC 2nd National (special signal for regional centres)			
English East		N+S	N+S
English West		N+S	N+S
French East*		S	S
French West*		S	S
CTV Network Dist.*	S	S	S
CTV Return Feed*		S	S
Gloval Dist.*	Montreal-West	Trans-Canada	Trans-Canada
Other TV*	S	SX2	SX4

* These entries are a requirement for service in Southern Canada only, all other services in the table require satellite facilities since microwave facilities do not extend to the northern areas which require the service.

[redacted]

the implication is that the service can only be provided by means of satellite because it covers areas of northern Canada which cannot economically be served by terrestrial means. If the entry is "S" the service is required in areas of southern Canada which are served by both satellite and terrestrial systems. These are the services for which the study must determine the most cost-effective transmission medium. An entry "N + S" indicates that the service is required in both northern and southern areas. It is therefore the subject of decision only for the southern areas.

A.3.1.1 CBC REQUIREMENTS

The requirements included here are for distribution from national to regional network centres and for regional distribution from arctic regional centres. Regional distribution in the south is currently achieved mainly by means of 2 GHz, 7 GHz, or 11 GHz analogue microwave radio or by off-air pick-up, none of which are part of the long-distance network for the purposes of this study. Thus, although regional distribution in the south could be accomplished by satellite, the trade-offs involved do not fall within the original terms of reference of the study. (In fact we were requested towards the end of the study to look at the problem of southern regional distribution. This was done by determining the effect of this requirement on satellite design and cost. Cost trade-offs with the terrestrial network were not carried out.)

The various CBC services are discussed below.

CBC Arctic Regional

For each service one-way channels to points which can only be served by means of a satellite. The channels originate at the appropriate Arctic Regional Centres as follows:

English east	-	Frobisher
English west	-	Yellowknife Inuvik Whitehorse (only one transmission at any one time)
French	-	Sept Iles

CBC National Distribution

For each service a one-way channel from the national centre to the regional centres as follows:

English - Toronto	to	Vancouver
		Edmonton
		Regina
		Winnipeg
		Montreal
		Halifax
		St. John's, Nfld.
		Yellowknife
		Inuvik
		Whitehorse
		Frobisher
French - Montreal	to	Vancouver
		Edmonton
		Regina
		Winnipeg
		Toronto
		Moncton
		Sept Iles

CBC National Omnibus

The CBC proposes to introduce two omnibus channels for the purpose of transmitting programme material from one regional or national centre to another. Thus the requirement is for two half-duplex channels, each interconnecting all 14 regional and national centres listed above under CBC National Distribution. If these channels were provided by terrestrial means they would be full-duplex since a microwave transmission system cannot provide half-duplex channels. This is also true of microwave back-haul to satellite ground stations and the ground stations themselves. A satellite transponder, however, is a half-duplex facility. A terrestrial omnibus would also allow multiple simultaneous usage of disjoint sections of the facility.

CBC 2nd National Network

According to the joint DOC/CBC study this service, if it is introduced, will probably be made available to remote areas by means of a high-power direct-broadcasting satellite transponder whose signal could be picked up by ground receivers of modest dimensions and cost, suitable for community applications. For small communities in remote areas it might well be the only CBC service available. For larger population centres it might also be made available as an alternate service via the CBC regional centres. In this case the regional centres might receive the signal from the direct-broadcasting transponder and redistribute a slightly modified programme to stations in the region. If this were done then a trans-Canada feed would not be required. On the other hand it might be distributed by a separate feed to regional centres in the south and this could be done by either satellite or terrestrial means. This might be done at the same time or after the service was distributed by means of a high-power transponder. Since the intentions of the CBC are not determined at this time the requirement is included in the matrix for satellite/terrestrial trade-off purposes in the late 1980's. In this case the requirements would be as follows:

a)	English west:	Toronto to:	Winnipeg Regina Edmonton Vancouver Whitehorse Yellowknife Inuvik
b)	English east:	Toronto to:	Montreal Halifax St. John's, Nfld. Frobisher
c)	French west:	Montreal to:	Winnipeg Regina Edmonton Vancouver
d)	French east:	Montreal to:	Sept Iles Moncton Toronto

<u>CTV Network Distribution</u>

CTV is an English language network of independent stations with network headquarters at Toronto. Thus the prime requirement is a feed from Toronto to all stations. Since the network already includes every node of the DLDCNS model, expansion to other cities, which are not nodes, would not affect the requirements as we model them. The requirement for this service is therefore a one-way channel from

Toronto to: St. John's, Nfld.
Halifax

Sydney
Moncton
Montreal
Ottawa
Sudbury
North Bay
Kitchener
Winnipeg
Regina
Saskatoon
Calgary
Edmonton
Vancouver

CTV Return Feed

CTV may eventually require a return feed from all its stations to Toronto for the purpose of assembling programme material. This is postulated as a return channel chaining all stations east of Toronto back to Toronto and a similar one for all stations west of Toronto.

Global Distribution

Global presently serves locations in southern Ontario only. This is represented by the entry "ONT." in the tables and below. We have assumed that here is a possibility of expansion in two stages for the purposes of our study. These stages are represented by items "MONTREAL-WEST" and "TRANS-CANADA" in the tables and below.

Major centres of English speaking population and wealth are selected first since this is a commercial, English language network.

ONT.	A one-way channel from Toronto to:	London Ottawa
MONTREAL-WEST	A one-way channel from Toronto to:	London Ottawa Edmonton Calgary Winnipeg Vancouver
TRANS-CANADA	A one-way channel from Toronto to:	London Ottawa Edmonton Calgary

Winnipeg
Vancouver
Montreal
Halifax
Moncton
Regina
Saskatoon

Other TV

In this area we have received no data whatsoever. Both long-distance interconnection of cable operators and ETV facilities are dependent on political and commercial developments of which we cannot be aware at the present time. It is also clear that many such possible requirements could be handled by air transportation of video-tape and film. We have therefore relied on subjective judgements in making forecasts.

The basic facility we assume is a half-duplex omnibus connecting all the following population centres which are nodes of the network model. Further distribution would not affect long-distance facilities. The nodes are:

Vancouver	Montreal
Edmonton	Quebec City
Calgary	Moncton
Saskatoon	Halifax
Regina	Sept Iles
Winnipeg	Sydney
Windsor	St. John's, Nfld.
Sudbury	
Toronto	
Ottawa	

We do not imply, of course, that all centres are likely to be interconnected in a single step but since we can have no indication of which would come first we have treated them all equally. An entry "S" in the table implies one such facility, "S x 2" two facilities and "S x 4", four facilities. Since these are half-duplex facilities the same comments apply as in the case of the CBC omnibus.

A.4 NORTHERN COMMUNICATION REQUIREMENTS

Two types of communication requirements are considered in this study. These are:

[redacted]

i) northern television requirements within northern Canada, and between northern and southern Canada,

ii) voice circuit requirements between established communities and northern Canada, and between these communities and southern Canada.

Communication requirements for data collection and to portable and mobile terminals are not considered.

The television requirements are estimated above in Section A.3.

Very little information was available on which to base estimates for thin-route voice circuit requirements in the 1980's. Because of this, the requirements were based on the following assumptions:

i) the two transponders presently allocated for thin route voice transmission on the Anik satellite will be fully utilized by 1980;

ii) circuit requirements will continue to increase throughout the 1980's, with the rate of increase different for the maximum, preferred and minimum forecasts;

iii) because of the large investment in ground stations in the Arctic at the present time, and the expected increase in this expenditure from now to 1980, it is expected that the satellite in the 1980's will use transponders similar to those on Anik for thin-route voice traffic.

The network requirements for thin-route voice traffic are given simply in terms of the estimated number of Anik-like satellite transponders, rather than as a more detailed traffic matrix. This is the only estimate required for the present study, since cost considerations rule out the possibility of terrestrial communication links to the many scattered Arctic communities.

The estimated number of satellite transponders required for this service is given in Table A.22.

[redacted]

Table A.22

Number of Anik-Like Transponders Required
for Thin-Route Voice Traffic
in Northern Canada

Forecast	1980	1985	1990
Maximum	3	4	6
Preferred	2	3	4
Minimum	2	2	3

[redacted]

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5. AUTHOR(s): R.V. Baser, R.R. Bowen, R.L. Hutchison, A.R. Kaye, T.A.J. Keefer, G.A. Neufeld, J.L. Thomas, E.A. Walker, P.R. Whalen

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