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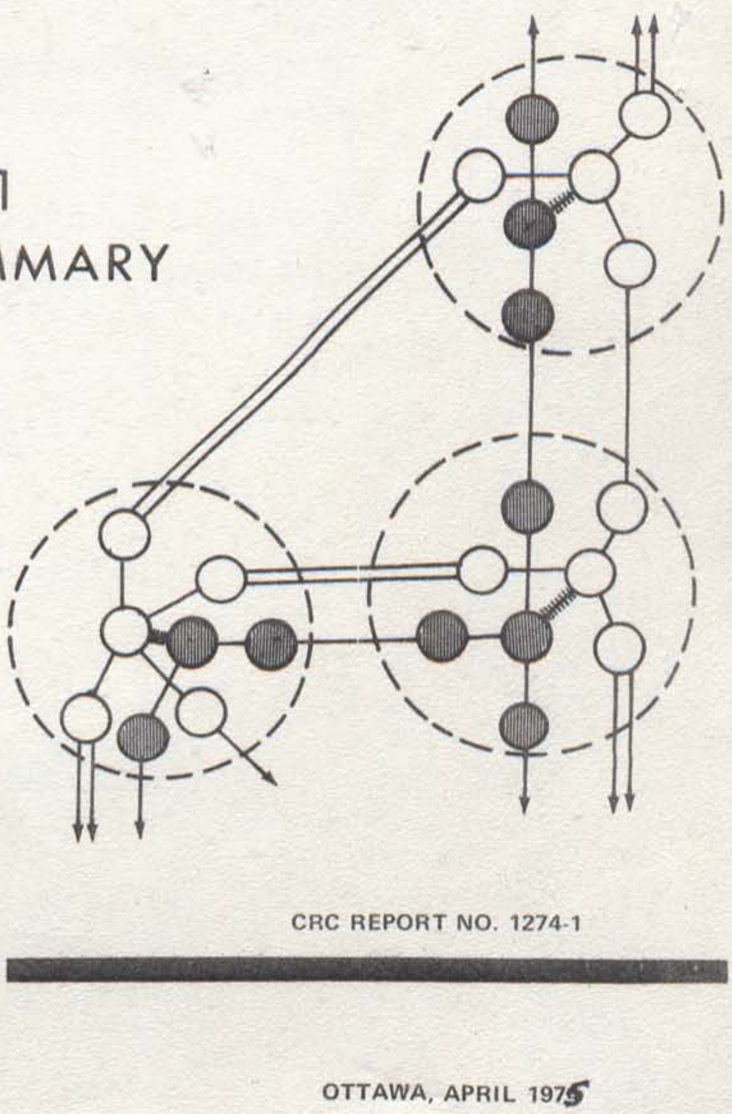
Communications Research Centre

DOMESTIC LONG DISTANCE COMMUNICATIONS NETWORK STUDY

VOLUME 1
EXECUTIVE SUMMARY



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OTTAWA, APRIL 1975

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COMMUNICATIONS RESEARCH CENTRE

DEPARTMENT OF COMMUNICATIONS
CANADA

DOMESTIC LONG DISTANCE COMMUNICATIONS NETWORK STUDY

VOLUME 1 – EXECUTIVE SUMMARY

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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NOTE

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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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ABSTRACT

The most cost-effective satellite systems 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 continue 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 million 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 terrestrial 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.

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CHAPTER 1

1. INTRODUCTION

1.1 OBJECTIVES AND ACCOMPLISHMENTS OF THE STUDY

In December 1972, Communication Systems Engineering (now Communications Systems Research and Development) was called upon to assist the Planning Branch in a project to be called the Domestic Long Distance Communications Network Study (DLDCNS). The broad objectives of the study were stated to be;

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

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

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

The time-frame upon which we focussed our attention was the early and mid 1980's, the time-frame of the next Canadian domestic communications satellite. As well, we considered evolution in the late 1970's, and in the late 1980's to early 1990's, to ensure that there would be smooth evolution of the postulated network and no large economic penalty outside the time-frame of prime interest.

To meet the objectives of the study investigations in several areas were carried out. These included:

a) estimation of both the types of traffic and the amounts of traffic likely to be carried on the Canadian long-distance satellite/ terrestrial network in the 1980's;

b) evaluation of the types of terrestrial transmission media and types of operational communications satellites that are likely to be available in the late 1970's and 1980's and of the costs of those media;

c) development of a precise and workable description of what is the "best" evolution of the network;

d) investigation of the non-economic constraints on evolution of the network, such as:

   i) survivability of the network,

   ii) adequate level of service throughout the network,

[redacted]

iii) conservation of the available spectrum,

iv) institutional arrangements among the common carriers and major communications users;

e) development of a tractable and yet complete model of the long-distance network, and of the analytic tools with which to optimize the network;

f) synthesis of several attractive network evolutions, using the above data and techniques.

In carrying out the above, the original objectives of the study were met, and several other important results were obtained while striving for the primary objective. The following "direct" results were obtained:

i) Several cost-effective evolutions of the network were determined, and the salient features and costs of these network evolutions were estimated;

ii) the most cost-effective of these network evolutions, which includes the use of three in-orbit Anik-like satellites in the 1980-87 time-frame, was examined in considerable detail, and found to be attractive over broad variations of network traffic and system costs;

iii) knowledge of the most cost-effective use of the various frequency bands available for satellite transmission in Canada was improved significantly, as was the knowledge of Canadian requirements for new frequency bands for high-capacity terrestrial long-haul systems;

iv) the sensitivity of the cost-effectiveness of the recommended network evolution to variations in many technical, economic, and political factors was examined.

As well as these "direct" results, several important by-product results were obtained. These include;

i) valuable data-bases of anticipated voice-traffic in Canada in the next decade, and of the capabilities and costs of several transmission media;

ii) algorithms and strategies were developed which can be modified to be used to solve other communications network problems.

1.2 OUTLINE OF THE EXECUTIVE SUMMARY

In chapter 2 the requirements on the network and constraints on the network evolution are described. A description of what is meant by "best" or "most cost-effective" network, and how that network was determined, is given in chapter 3. The important results are presented in chapter 4.

1.3 OUTLINE OF THE FULL REPORT AND APPENDICES

The complete report is being published in five volumes. Volume one is this executive summary.

Volume two is the full report, and Appendix A. The full report is a much more detailed description of the assumptions, methods, and results that are presented in this summary. Appendix A is an estimate of the traffic requirements of the network in 1973, 1980, 1985 and 1990.

The Canadian terrestrial network at the present time and its probable expansion in the 1980's is described in Appendix B, which will become volume three. The capital costs of present microwave radio systems, metropolitan junction systems, and possible new cable, radio, and waveguide systems in the 1980's, are described in this appendix.

Potential satellite systems, and their costs, are described in Appendix C. Included is a description of a set of empirical relations used to determine the cost and weight of a communications satellite. Capabilities and costs of satellite ground stations are described in Appendix D. These two appendices will be published in volume four.

Sensitivity of the cost-effectiveness of the recommended network evolution to several technical, economic, and political factors is discussed in Appendix E. A detailed description of the methodology used to determine the most cost-effective network is presented in Appendix F. These appendices will be published in Volume five.

CHAPTER 2

2. REQUIREMENTS AND FACILITIES OF THE NETWORK IN THE 1980's

2.1 TRAFFIC REQUIREMENTS

In DLDCNS we have determined the most cost-effective expansion of the network to meet the following types of traffic requirements in the 1980's.

1) Nationwide television distribution of CBC, CTV, and Global TV, including the proposed CBC omnibus facility and distribution to and from regional centres in northern Canada,

2) distribution of CBC regional television programs in northern Canada,

3) long-haul distribution of educational television programs and of programs between cable TV companies,

4) thin-route voice traffic between established communities in northern Canada, and between these communities and southern Canadian cities,

5) long-haul domestic voice and data traffic in southern Canada, and

6) COTC voice traffic between Halifax and Toronto.

These are the types of traffic which are or would be carried on the following systems:

a) The TCTS Interprovincial and Trans-Canada 4 GHz microwave radio systems,

b) the CNCP 6 GHz microwave radio system,

c) the LD-4 coaxial cable system between Toronto and Montreal, and

d) the Telesat Canada satellite system.

Short-haul voice traffic between locations less than several hundred miles apart was not considered, because it is not carried on the above systems, and is very unlikely to be carried on a satellite system in the 1980's. The excluded traffic includes voice and data traffic between the USA and the nearest major Canadian switching centre.

A major segment of traffic not considered in the initial stages of the study is the distribution of CBC television signals from regional centres to CBC stations in southern Canada. Because of this, neither our model of the satellite/terrestrial network nor our network optimization algorithms were designed to deal with this traffic. However, late in the study, at the request of the DG/TSP, the marginal costs to add a regional television distribution capability to the satellite system were estimated.

Estimates of the magnitude of the above types of traffic throughout the 1980's were required so that the cost-effectiveness of various network evolutions could be compared. These estimates had to be based on incomplete knowledge of traffic before 1975, and then extrapolated fifteen years into the future. Because of the resultant uncertainty in the estimates, three separate estimates were made:

i) A maximum estimate, based on an exponential extrapolation of available voice-traffic data and including all television traffic being considered by the television corporations and agencies;

ii) a minimum estimate, based on linear extrapolation of voice-traffic data and a very modest increase in television traffic; and

iii) a preferred or expected estimate, the geometric mean of the maximum and minimum estimates.

It is expected that television distribution and thin-route transmission services to many of the established northern communities will be by a satellite system with Anik-like transponders, because

i) provision of a similar service by a terrestrial network would be prohibitively expensive, and

ii) many ground stations are already in the north to operate in such a system.

The expected number of Anik-like transponders for these services is shown in Table 2.1. Also included in Table 2.1 are the satellite transponders required to transmit the CBC first national programs to and from the CBC northern regional centres.

The expected number of television signals to be distributed across Canada in the 1980's is shown in Table 2.2. Note that the CBC first national programs are included in both Table 2.1 and Table 2.2.

TABLE 2.1

Expected Number of Anik-like Satellite Transponders Required to Meet Northern Television Distribution and Thin Route Requirements

Time	Forecast		
	Minimum	Preferred	Maximum
1980	6	7	8
1985	7	8	10
1990	8	10	11

TABLE 2.2

Expected Number of Television Signals Requiring Nationwide Distribution in the 1980's

Time	Forecast		
	Minimum	Preferred	Maximum
1980	5	7	8
1985	7	8	13
1990	9	13	15

The long-haul voice traffic in Canada in the 1980's is modelled as traffic between the following fifteen major population centres: Vancouver, Edmonton, Calgary, Saskatoon, Regina, Winnipeg, Sudbury, Toronto, Windsor, Ottawa, Montreal, Quebec City, Moncton, Halifax, St. John's. Most of these cities are expected to be major nodes connected by high-usage trunks in an evolving three-level TCTS routing hierarchy by the 1980's, so the present TCTS routing strategies were not considered in routing traffic between these centres. Further, these centres were assumed to be "catchment centres" for long-haul traffic generated near them.

Minimum, maximum, and preferred estimates of the end-to-end voice circuit requirements between these fifteen centres in 1973, 1980, 1985 and 1990 are given in Appendix A of the main report. As an example, the estimates of voice circuit requirements between Vancouver and Toronto are given in Table 2.3. Estimates of the sum-total of all the end-to-end voice circuit requirements are shown in Table 2.4.

TABLE 2.3

Expected End-to-End Voice Circuit Requirements Between Vancouver and Toronto

Time	Forecast		
	Minimum	Preferred	Maximum
1973		240	
1980	470	850	1,500
1985	630	1,900	5,600
1990	800	4,100	21,000

TABLE 2.4

Expected Total End-to-End Voice Circuit Requirements

Time	Forecast		
	Minimum	Preferred	Maximum
1973		15,000	
1980	24,000	34,000	43,000
1985	31,000	61,000	120,000
1990	39,000	110,000	320,000

It is estimated that 84% of the voice and data traffic is carried on the TCTS network, and 16% on the CNCP network. No change in this division of traffic is assumed to take place in the 1980's.

2.2 TRANSMISSION MEDIA FOR THE NETWORK IN THE 1980's

New transmission systems are expected to be introduced into the Canadian long-haul network to meet the expanding requirements outlined above.

The present terrestrial long-haul transmission media are 4 GHz and 6 GHz analog microwave systems. The LD-4 digital coaxial cable will soon be put into service between Toronto and Montreal. New terrestrial transmission media that could be introduced into the network in the 1980's are:

1) 8 GHz digital radio system, a medium capacity add-on to the 4 GHz analog system;

2) a 12 GHz high capacity digital radio system;

3) an analog coaxial cable system such as the L-4 or L-5 systems of A.T.&T;

4) a digital, circular, millimetre waveguide system;

5) a high-capacity optic-fibre system;

6) conversion of the 4 GHz and 6 GHz analog radio systems to medium-capacity digital systems, or perhaps to higher capacity analog systems by using SSB/AM;

7) 6 GHz radio overbuild of at least the Interprovincial 4 GHz radio system.

These are the *possible* systems that were considered. As discussed in chapter 4 below, and in more detail in chapter 4 of the full report, it is likely that (1), the 8 GHz digital radio add-on system, will be introduced about 1980. Following that, systems (2), (6) or (7) are likely to be introduced in the late 1980;s and the 1990's.

As well, there are many types of communications satellites that could be used in conjunction with these terrestrial systems. They are distinguished from a network viewpoint by:

a) How many identical operational satellites are used;

b) which of the 4/6 GHz, 12/14 GHz, and 18/30 GHz frequency bands are used;

c) whether or not dual polarization, spot beams, and/or source encoding techniques are used to increase the satellite system capacity; and

d) whether multi-purpose or separate special-purpose satellites are used.

Only satellites which are currently in operational use, are being produced, or have been suggested as a feasible operational satellite by a satellite manufacturer were considered for operational use in 1980. In contrast, all advanced satellite design techniques currently undergoing investigation were assumed to be available for operational use in 1987.

Use of conventional launch vehicles is assumed, although use of the shuttle and tug by 1987 would not change the form of the network significantly.

2.3 ANTICIPATED CHANGES IN THE TCTS NETWORK

Three significant changes are expected to take place in the TCTS network, which will significantly effect the development of the long-haul transmission network. These are:

1) As part of a conversion to a digital network, all expansion of the terrestrial network is expected to be with digital systems by 1980.

2) The routing hierarchy is expected to become a three-level one in the 1980's, with most of our major traffic centres becoming a highest level node in the TCTS network.

3) New solid-state digital switching machines are expected to be introduced at major traffic centres in the 1980's. With these switches the present problems associated with use of satellite voice circuits will be avoidable.

2.4 THE DLDCNS MODEL OF THE SATELLITE TERRESTRIAL NETWORK

The model of the satellite/terrestrial network used in the DLDCNS is shown in Figure 2.1. A node in the network is one or more of the following:

1) A major centre for voice traffic,

2) a network television transmission point, or

3) a major branch in the network.

In addition a virtual node (number 21 in Figure 2.1) was added to represent the many northern communities. Satellite ground stations could be added or removed from any network node. A more detailed drawing of the network in the Toronto-Ottawa area is shown in Figure 2.2.

CHAPTER 3

3. OPTIMIZATION OF THE NETWORK

3.1 MINIMUM-TOTAL-COST NETWORK EXPANSION

The network was "optimized" by determining how the network should evolve such that the present value of the expenditure of national resources in the 1980's is minimized. Specifically, the time-interval over which network costs

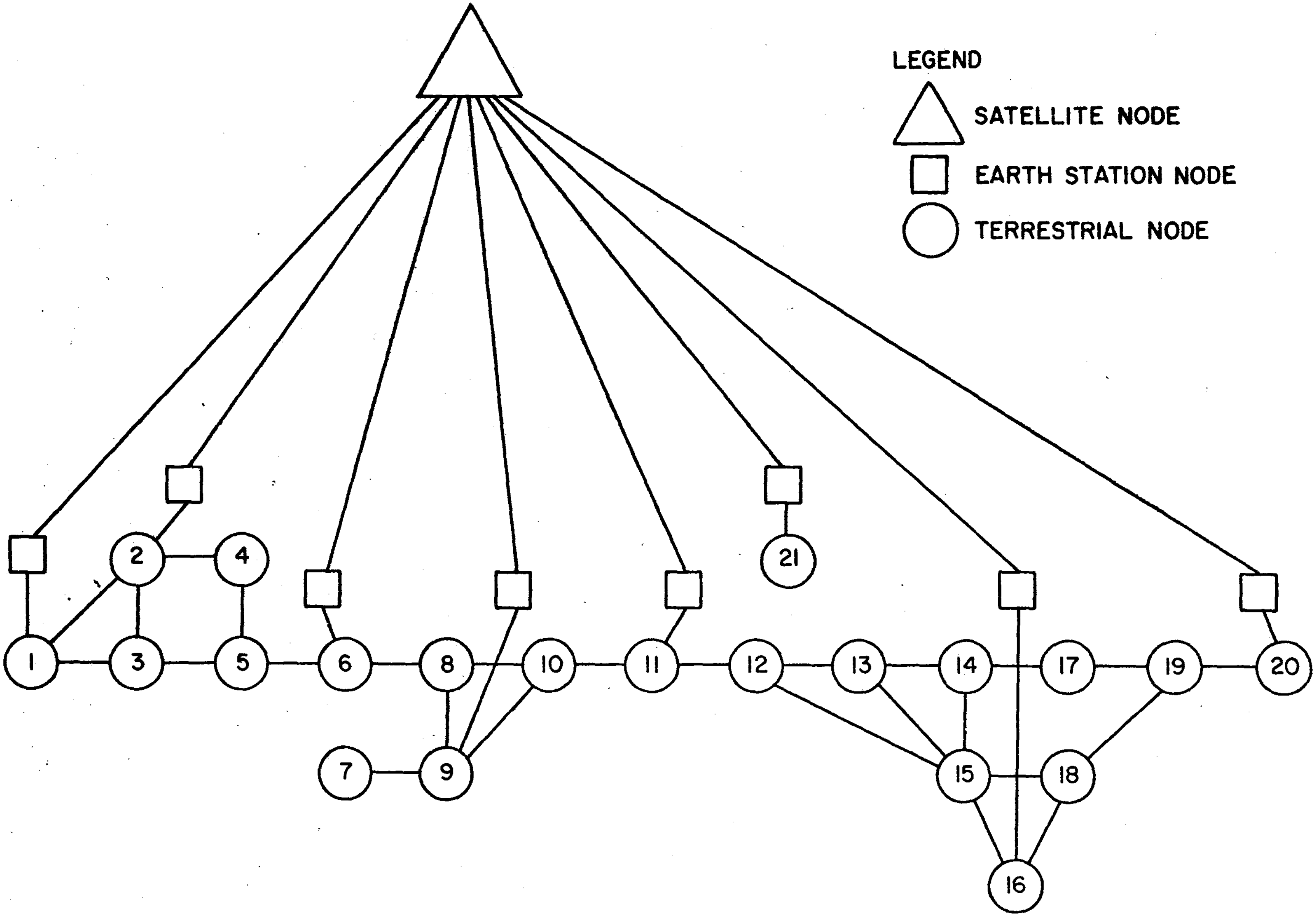

Figure 2.1. The Complete Network Model

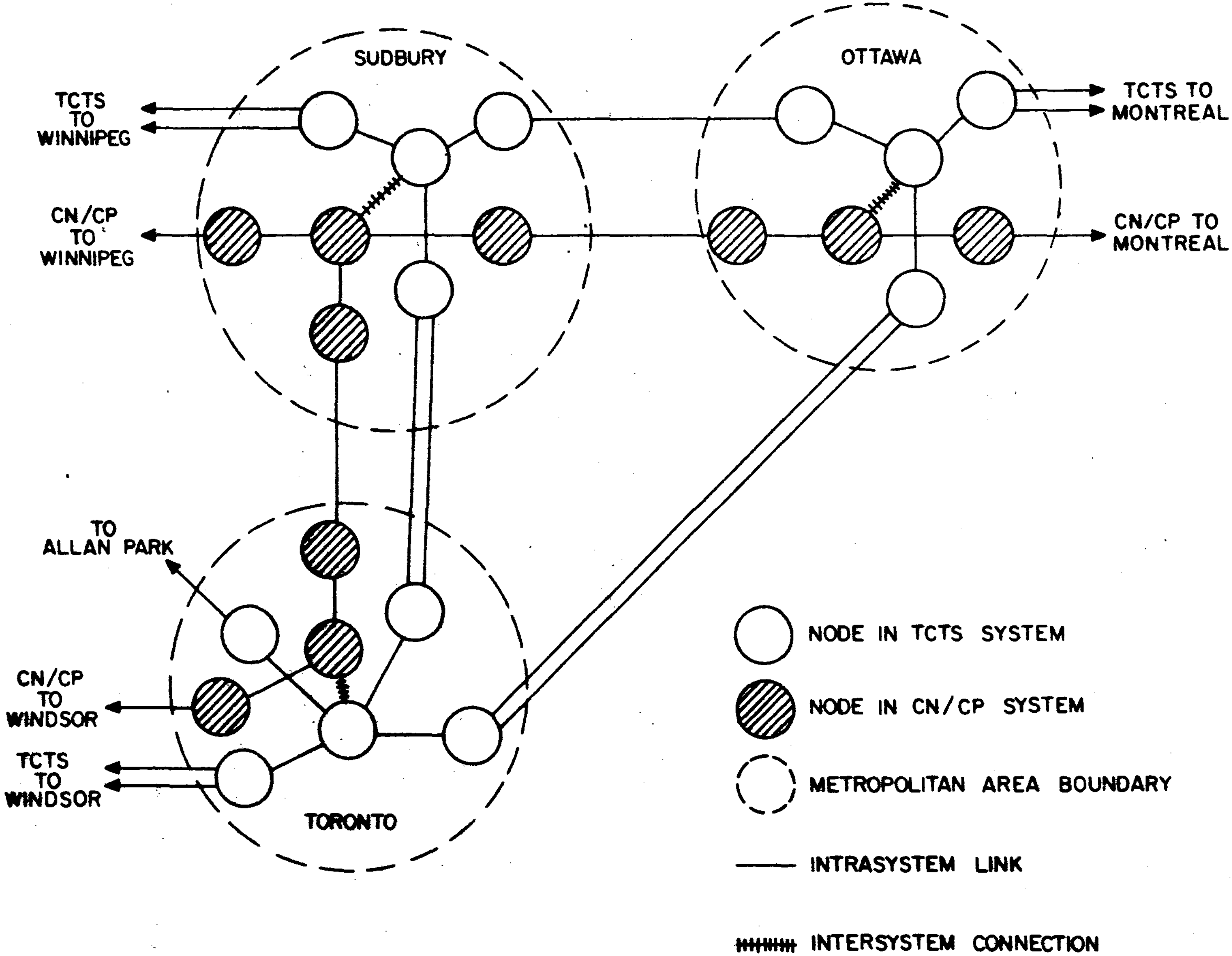

Figure 2.2. Detail of Network Model in Toronto-Ottawa Area

were considered was 1980 to 1994, the expected lifetime of two satellite systems after the present Telesat Anik system.

Evolution of the network in the intervening 1975 to 1980 period was not optimized, because plans for additions in this interval are too far advanced for a study such as DLDCNS to have an effect. Because of this, we did not take into account the unretired debt of systems existing in 1980 in our tradeoffs because it is an unavoidable cost in all possible networks. Because we sought a network evolution which would result in minimum expenditure of national resources, the only costs considered were amortization of capital debt incurred in the 1980-94 interval, and maintenance and operating (M+O) costs of existing equipment in the field. Other items which enter into a *rate* determination or the optimization of the corporate position of an individual carrier, such as corporate taxes, corporate profit, municipal taxes, etc. were not considered.

The actual network optimization technique used was to determine the *annual* cost of each possible link in the network shown in Figures 2.1 and 2.2, taking into account amortization and M+O costs. A network was then synthesized to meet the estimates of voice circuit requirements in such a way that the total annual costs were minimized. In this way several attractive network scenarios were determined. These were then compared by determining the present value of the cost of each.

In determining whether a block of traffic is routed through path A or path B of the network, it is very important that *marginal* costs rather than *average* costs are used; the converse does not result in a minimum-total-cost network. The significance of the difference in the context of the Canadian network is due to two factors:

1) A significant amount of northern voice and television traffic will be carried by the satellite system whether or not any southern traffic is carried by satellite.

2) Considerable economy of scale of satellite systems is attainable in the context of the Canadian network. Terrestrial expansion will be by 4 GHz, 6 GHz and 8 GHz microwave systems whether or not the satellite carries significant southern traffic. The economies of scale have already been achieved in these networks since the infrastructure has already been built; only marginal costs are relevant, and these marginal costs per voice circuit are to a first approximation independent of the amount of traffic through the systems.

3.2 NON-ECONOMIC CONSTRAINTS ON THE EVOLUTION OF THE NETWORK

There are several constraints or necessary characteristics that any expansion of the network must have, apart from being of minimum total cost or close to minimum cost. These are:

1) There must be smooth evolution of the network,

2) the radio spectrum must be used wisely,

[redacted]

3) the network must meet certain quality and survivability specifications.

3.2.1 Network Survivability

The network survivability requirement is quite important and requires further explanation, because it limits the amount of voice traffic through the satellite system in the late 1980's, and even in the early 1980's under maximum traffic growth conditions.

Network survivability requirements are well understood and defined for a strictly terrestrial network, and especially for a single chain-like network such as the Canadian network shown in Figure 2.1. In the Canadian TCTS network there are two independent parallel systems. If one system fails, the other must carry as much traffic as possible. All spare hot-standby radio channels would be used in such an event. Network survivability is about 60% in that system, in that the transmission capacity after the catastrophic failure is 60% of that before the failure. If the network had three parallel systems, equally loaded, its survivability would be about 80%. This survivability refers to the network between two major nodes only, such as between Ottawa and Montreal. After a failure the rest of the network would be unaffected, except that it would be difficult to route traffic through the link in which one system had failed.

It should be noted that the survivability of the present CNCP network is zero, except for the possible re-routing of traffic through the TCTS network or the Anik satellite system. An even more serious situation is that there is at present no survivability whatsoever between St. John's and Cornerbrook.

The above network survivability considerations do not apply directly if a satellite system carries a significant amount of voice traffic, because a satellite failure would effect all parts of the network. No domestic satellite system to date has carried a significant amount of voice traffic, and so no network survivability rules for satellite use have been developed. Because of that we developed our own tentative set of rules, which seem to be similar to those being adopted for use in the European operational satellite system.

From a network survivability viewpoint, there are two kinds of satellite system. These are:

1) A system in which there is one operational satellite and an in-orbit spare.

2) A system in which there are two identical operational satellites plus a third in-orbit satellite as a spare. In such a system all major ground stations would have the capability to handle traffic from two satellites simultaneously.

The second system obviously has a better survivability than the first. The rules adopted for satellite system use in the network to carry voice traffic are as follows:

[redacted]

a) If a single satellite plus back-up are used, no more than 33 1/3% of all voice traffic through a network cross-section can be by satellite.

b) If a dual operational satellite system plus back-up are used, no more than 50% of all voice traffic through a network cross-section can be by satellite.

The six network cross-sections considered are shown in Figure 3.1. No cross-sections within the Windsor-to-Quebec City region were considered because it is not cost-effective to route traffic completely within that region by satellite.

CHAPTER 4

4. MINIMUM-COST NETWORKS FOR THE 1980's

The long-distance network in the 1980's will have the following general characteristics:

1) The present TCTS 4 GHz analog microwave radio system will likely continue to carry long-distance traffic, but is unlikely to expand above its present installed capacity, and certainly not above its installed capacity in 1980, as long as it remains an analog system. Conversion to a medium-capacity digital radio system in the late 1980's is a possibility.

2) An 8 GHz digital radio system, an add-on to the 4 GHz system, is expected to be used for expansion of the TCTS terrestrial network in the 1980's.

3) The CNCP 6 GHz analog radio system will meet CNCP's terrestrial long-haul transmission requirements throughout the 1980's.

4) A 4/6 GHz satellite system will be used to meet northern thin-route voice requirements and television requirements, and also to distribute network-quality television programs in southern Canada.

5) Medium-capacity and high-capacity voice circuit requirements between cities in southern Canada will be met by a combination of satellite and terrestrial systems; both can be used effectively. The growth of satellite and terrestrial systems to meet this requirement will depend on the relative costs of system augmentations, on network survivability requirements, and on institutional arrangements between the Canadian common carriers.

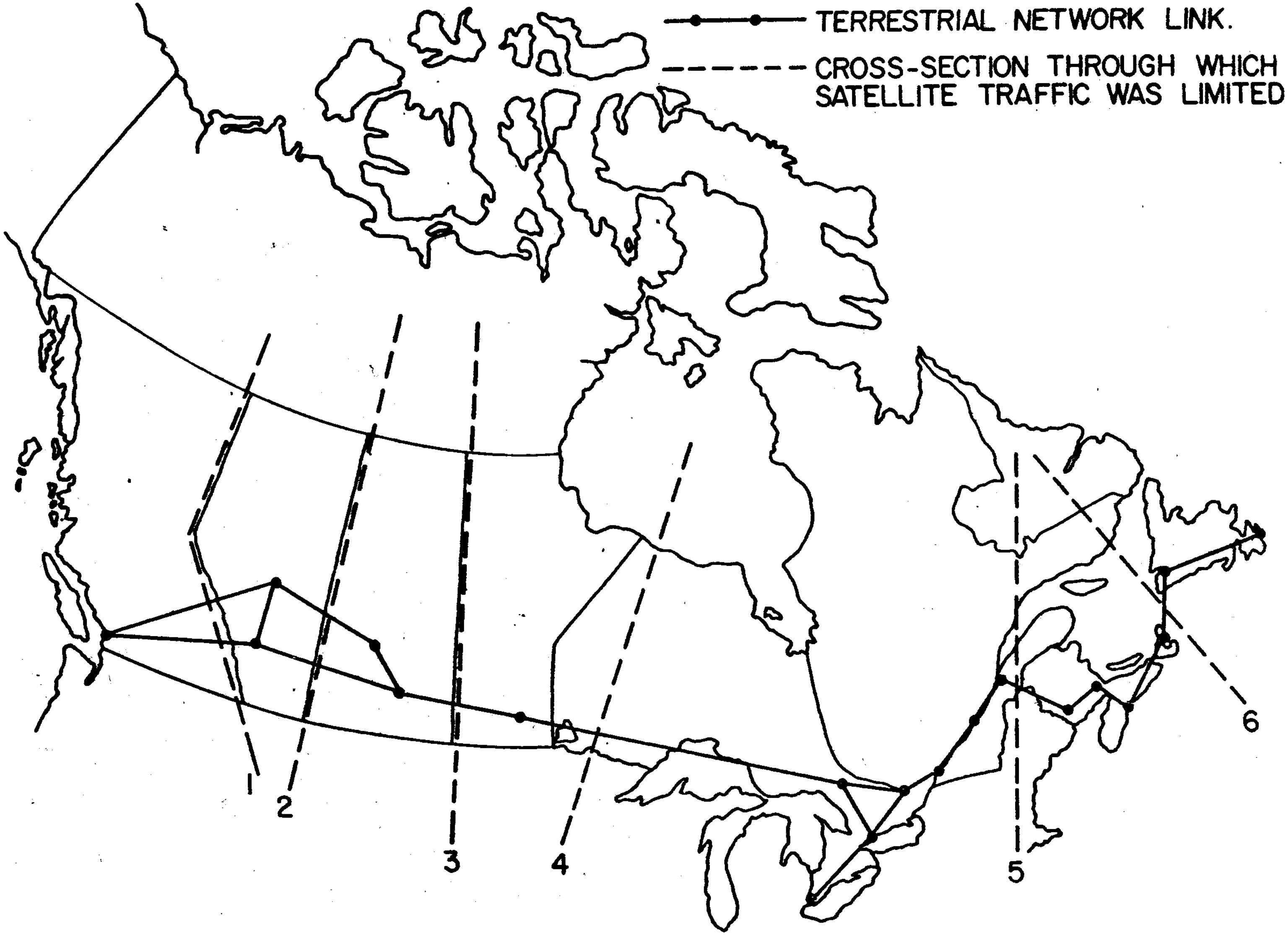

Figure 3.1. Trans-Canada Terrestrial Network and Cross-Sections of Limited Satellite Traffic

The satellite system to meet northern voice and television requirements, and to distribute television signals in southern Canada, is described in section 4.1. The costs and characteristics of this system form the basis upon which to determine the marginal costs of satellite system augmentation for voice transmission, since a satellite system is incontrovertibly the cheapest means of meeting these requirements.

Two scenarios of evolution of the network are presented in section 4.2, one of which has minimum total network cost, and the other is the likely network expansion if present institutional arrangements continue throughout the 1980's. The minimum-cost network is described in more detail in section 4.3.

The possibility of increasing the size of the satellite system to distribute CBC regional television programs in southern Canada is investigated in section 4.4.

The most cost-effective use of the frequency bands allocated for satellite use is discussed in section 4.5.

4.1 SATELLITE SYSTEMS TO MEET NORTHERN REQUIREMENTS AND SOUTHERN TELEVISION REQUIREMENTS

The satellite systems required to meet northern requirements only, and to meet both northern requirements and distribution of nationwide television programs in southern Canada, are listed in Table 4.1. One of the earliest and most conclusive results obtained in the DLDCNS is that it is cost-effective to distribute nationwide television signals in southern Canada through a 4/6 GHz satellite system with a Canada-wide antenna beam. This result holds for all foreseen variations in traffic requirements and system costs, and holds true when either marginal costs or fully allocated costs are used to compare satellite and terrestrial systems.

One could conclude from the above that the satellite system that might be used in Canada in the 1980-87 time-frame is one with two in-orbit augmented Anik satellites, followed in 1987-94 by two in-orbit satellites similar to that being built for RCA Globcom. The Anik satellite would be modified so that all 12 transponders could be used throughout the satellite's planned lifetime. (A larger prime-power system and redundant transponders would be required). Extensions of satellite capacity beyond this level are discussed in the following sections.

4.2 TWO NETWORK SCENARIOS FOR THE 1980's AND EARLY 1990's

Two possible networks for the 1980's and early 1990's are outlined and compared here. They are:

1) The network which has minimum total cost;

2) the network which would likely evolve if present institutional arrangements persist.

TABLE 4.1

Satellite Systems
To Meet Northern Requirements and Southern Television Requirements

Time	Service		Satellite Type	Annual Cost of Space Portion of satellite system (millions of 1973 dollars)
	Northern Voice and Television	Southern Nationwide Television Distribution		
1980-87	Yes	No	Fairchild 8 transponder satellite	9.6
1980-87	Yes	Yes	augmented Anik	10.7
1987-94	Yes	No	Anik	10.5
1987-94	Yes	Yes	RCA-type	14.8

The major difference between the two networks is that in the former it is cost-effective to route large amounts of voice traffic through the satellite, whereas in the latter virtually no voice traffic is routed through the satellite system. The reason for the difference is that if a hypothetical single carrier operated all national transmission facilities it would carry voice traffic on whichever system had lowest marginal costs. This is implicitly the point of view represented by our overall-minimum-cost approach, although institutional mechanisms other than a single carrier could be devised to achieve the same result. With a separate, satellite, carrier's carrier, however, circuits are not made available to the primary carriers at marginal cost. Rather, they would likely be made available at a fully-allocated cost multiplied by a factor to include profit and corporate tax of the carrier's carrier. The result is that the marginal cost of the primary carrier's own terrestrial systems would be much lower than the average lease rates for the satellite facilities.

The growth of the network would be as follows if the network were to have minimum total cost:

a) The satellite system would have three in-orbit Anik-like satellites in the 1980-87 time-frame, and three RCA-type satellites in the later 1987-94 time-frame. Satellite ground stations in southern Canada would be augmented to be capable of communicating through two satellites simultaneously.

b) About 9,000 voice circuits would be routed through the satellite system in 1985, and about 20,000 in 1990. The bulk of this traffic would be between Vancouver, Edmonton and Calgary in the west and Toronto and Montreal in the east.

c) Major expansion of the terrestrial network would be the 8 GHz digital radio system. This system would not saturate until the mid 1990's, except in the Toronto-Montreal corridor.

In contrast, if present institutional arrangements continue it is unlikely that there will be any voice traffic by satellite until presently installed terrestrial systems and any add-ons to those systems are saturated. This is not likely to occur until the late 1990's, if the 4 GHz microwave radio system is converted to a digital one and is augmented by a 6 GHz over-build as well as the 8 GHz overbuild. In this network scenario the satellite system between 1980 and 1994 is essentially that described above in section 4.1.

The economic basis of the difference in the two network scenarios is the significant economy-of-scale of satellite systems over the range of interest, and the satellite system requirements for northern Canada.

Over the interval 1980 to 1994, the network with the smaller satellite system would cost about $10 million (1973 dollars) more than the minimum-cost network. The difference between the cash-flows of the two network scenarios is shown in Figure 4.1. The network with the larger satellite system is more expensive initially, but less expensive over the longer period. As shown, this result is invariant over a wide range of discount rates.

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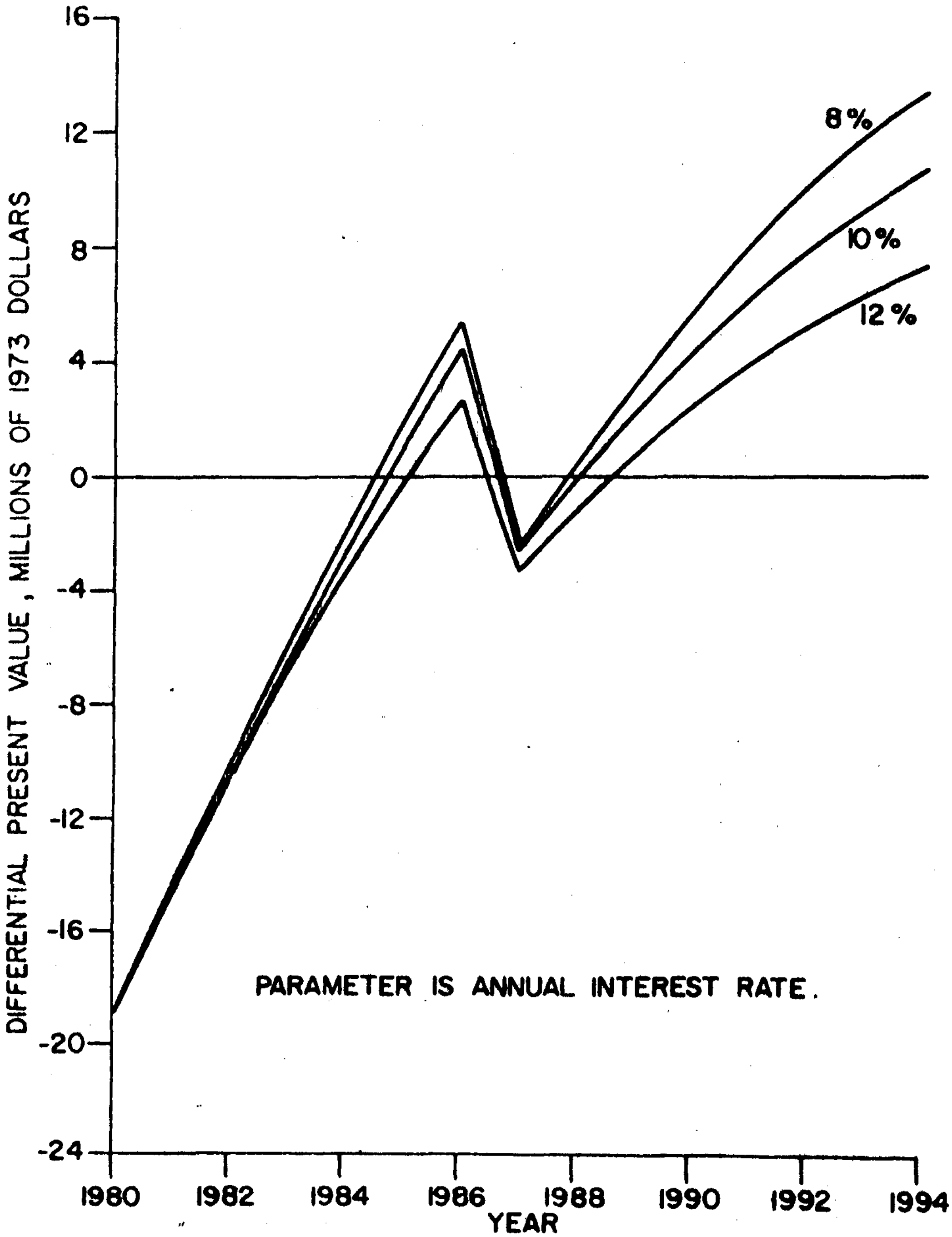


Figure 4.1. Cash - Flow of Additional National Expenditure Resulting from a Fully-Allocated-Costing Situation

[redacted]

4.3 THE MINIMUM-COST NETWORK

The evolution of the most cost-effective network, i.e. that network which meets the traffic requirements, network survivability requirements, etc. at minimum total cost, is of course very dependent on the rate of growth of traffic through the network. The minimum cost network to meet the expected or preferred traffic forecast is described first, and then changes in the network to meet the maximum and minimum forecasts are examined. The most cost-effective satellite system for the 1980-87 interval to meet this uncertain requirement is suggested.

Voice circuit requirements through the satellite system in the minimum-cost network to meet the 1985 preferred traffic forecast are about 9,200 voice circuits, as shown in Figure 4.2. (A TDMA subsystem would be used for medium-capacity voice traffic, and dedicated transponders for high-capacity voice links.) By 1990 voice circuit requirements through the satellite would increase to about 21,000 circuits, as shown in Figure 4.3. The amount of voice traffic through the satellite by 1990 is limited by the network survivability requirement. Voice circuit requirements through the TCTS terrestrial digital network in 1990 is shown in Figure 4.4, and 1990 requirements of the CNCP terrestrial network is as shown in Figure 4.5. Voice circuit requirements of the TCTS 4 GHz microwave radio analog system are expected to remain fairly constant throughout the 1980's at the level shown in Figure 4.6.

A satellite system with three in-orbit Anik-like satellites best meets the 1985 preferred satellite system requirements. An alternative satellite system that could be used is a system with two in-orbit satellites similar to the RCA Globcom satellite. That system is slightly less costly than that with three Anik-like satellites, but the latter is preferred for the following reasons:

1) From a network survivability point of view a satellite system with two operational satellites plus a spare is much better than a single satellite plus spare;

2) a system with two operating satellites would give better performance during solar eclipse and solar transit;

3) the dual-Anik system is simply a continuation of the present system, with no problems of initiating a new type of satellite.

If voice and television traffic grew as fast as predicted by the maximum traffic forecast, a satellite system with three in-orbit RCA-type satellites would be required in the 1980-87 period. In the later 1987-94 period a satellite system with three in-orbit hybrid satellites would be required. These satellites would have a 4/6 GHz subsystem with a Canada-wide beam for northern services and television distribution, and a 12/14 GHz subsystem with 0.5° spot beams for high capacity voice transmission. It is expected that the 12/14 GHz subsystem would handle about 80,000 voice circuits in 1990 in these circumstances.

In contrast, if voice and television traffic expanded as suggested by the minimum traffic forecast, the most cost-effective network would have two in-orbit Anik-like satellites in 1980-87, and two in-orbit RCA-type satellites in 1987-94.

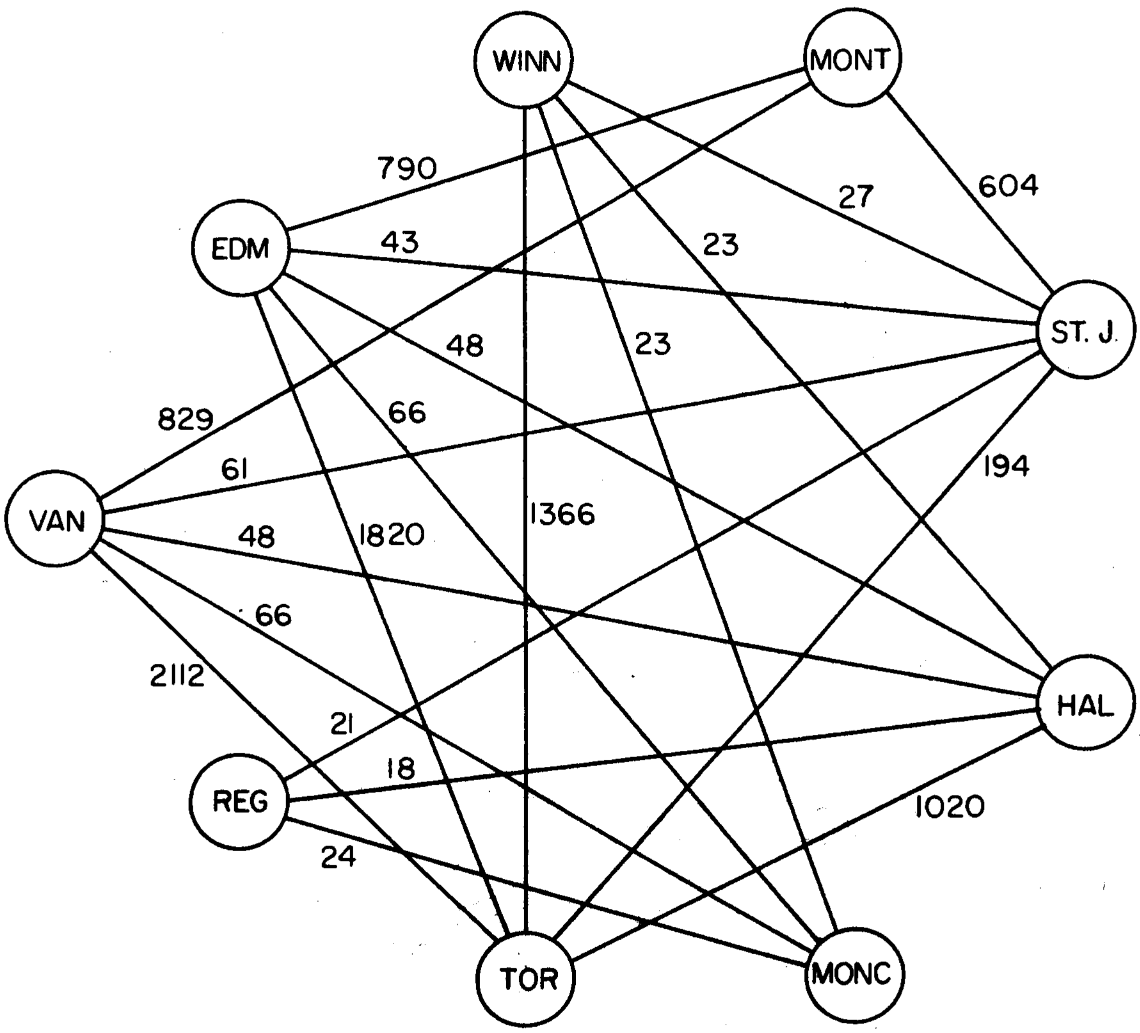


Figure 4.2. Voice Circuit Loading Through Satellite System in 1985

[redacted]

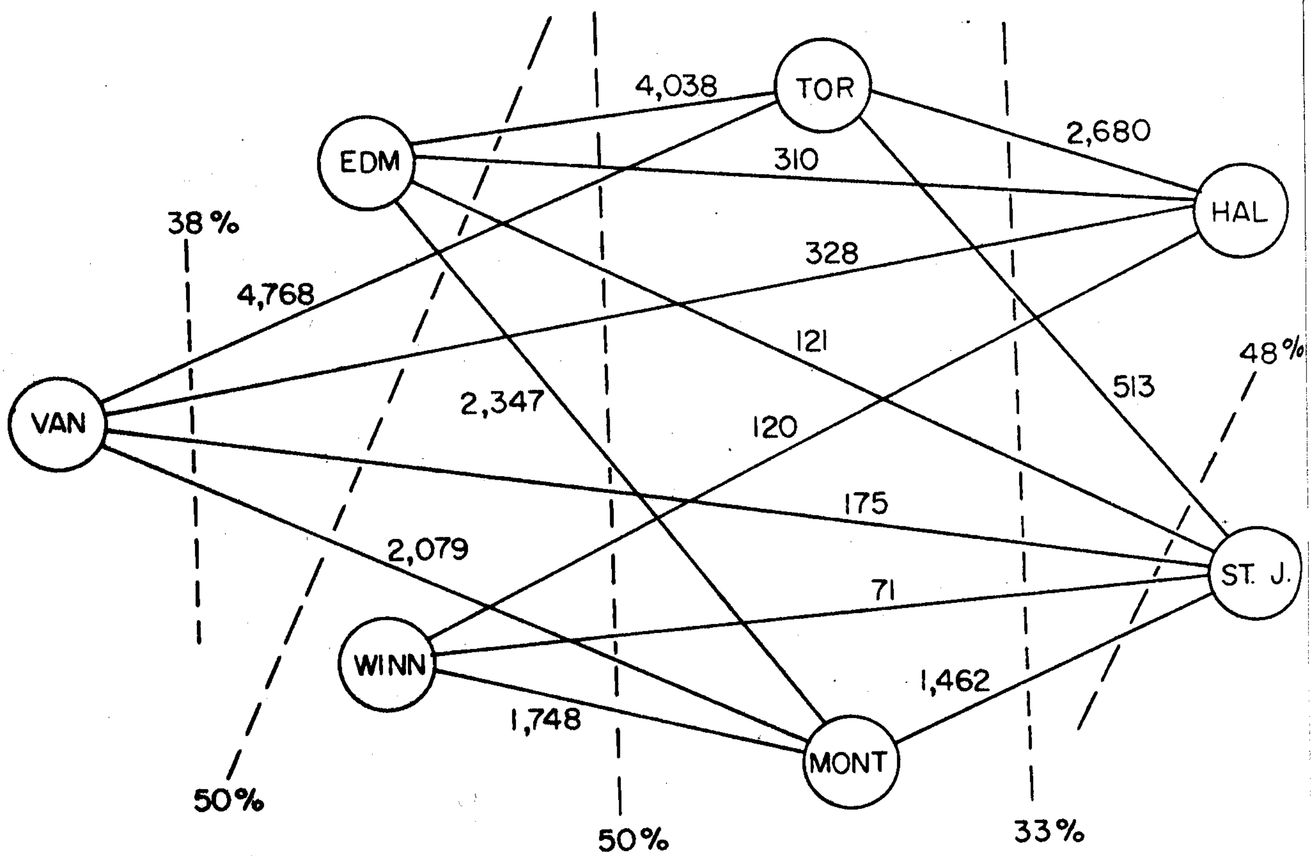
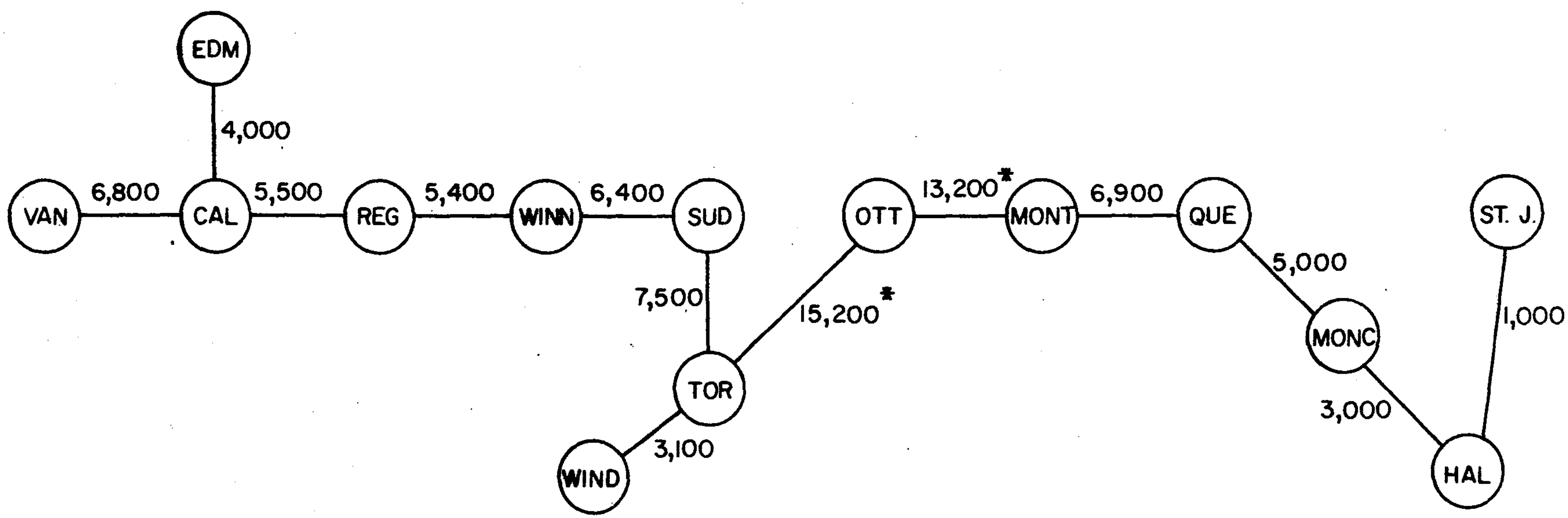


Figure 4.3. Voice Circuit Loading Through Satellite System in 1990

[redacted]



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

Figure 4.4. Expected Voice Circuit Loading on TCTS Digital Radio Network in 1990

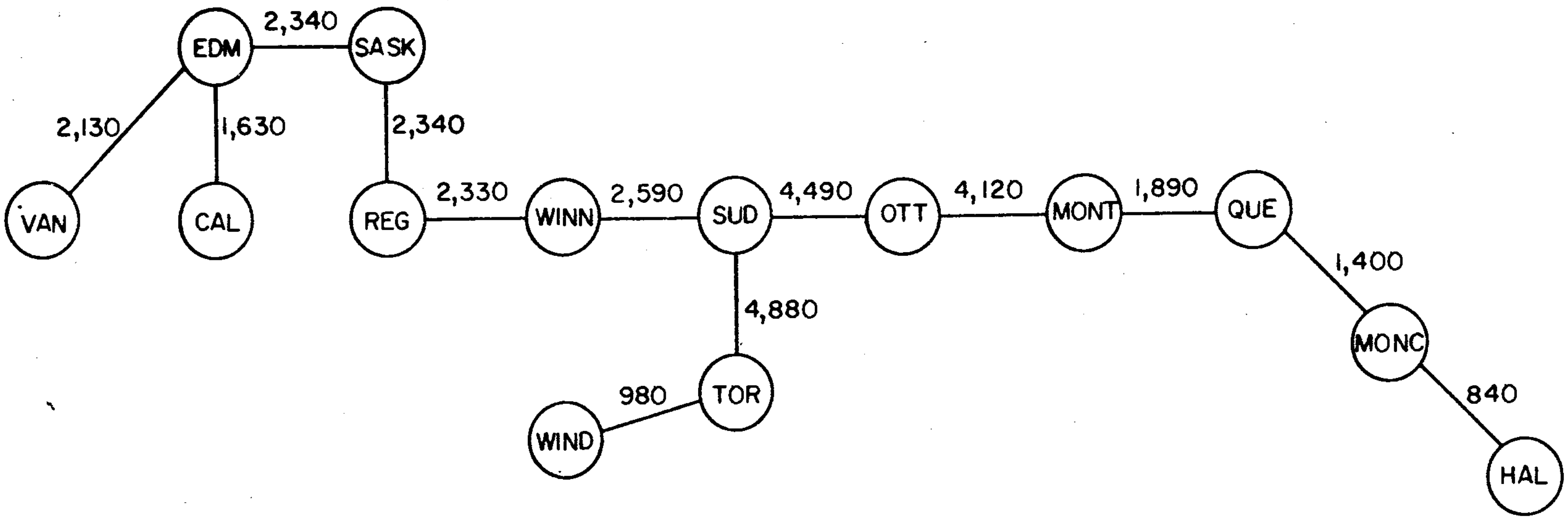
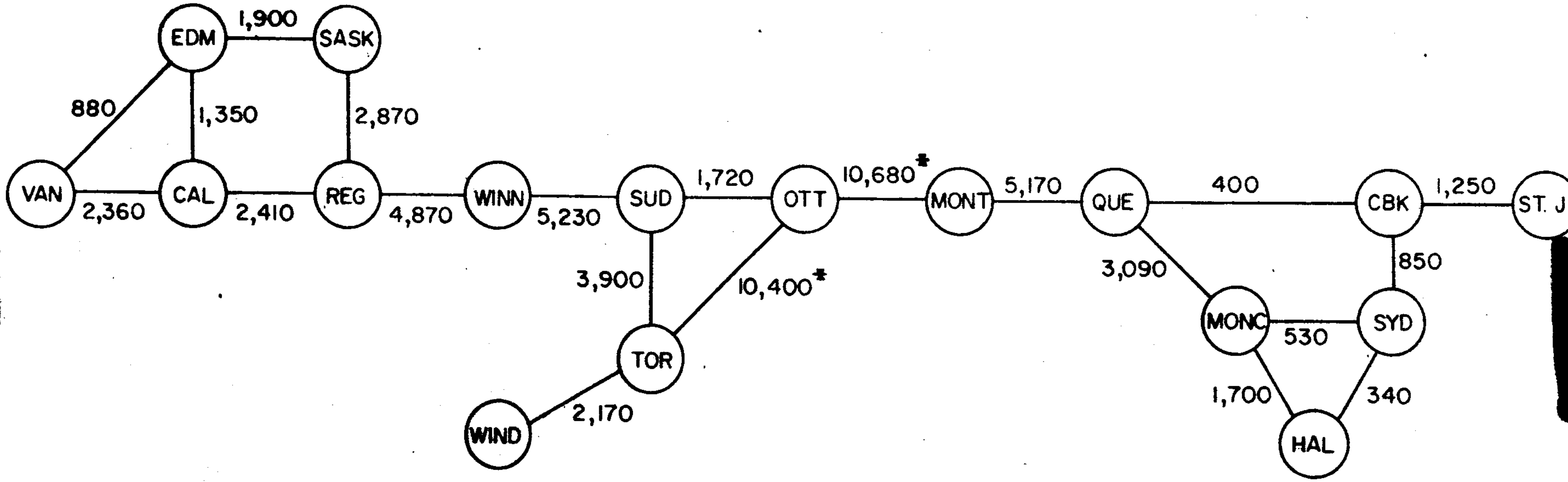


Figure 4.5. Voice Circuit Loading on CNCP 6 GHz Analog Radio Network in 1990



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

Figure 4.6. Voice Circuit Loading on TCTS Analog Radio Network in the 1980's

The choice, then, becomes that of using Anik-like satellites or RCA-type satellites in the 1980-87 period. The options, and the extra costs of choosing the more expensive option, are summarized in Table 4.2. It is our opinion that a satellite system using three in-orbit Anik satellites would be preferable, for the following reasons:

a) With such a system the network is very adaptable to variations in traffic requirements. (The launch of the third Anik can be delayed if traffic does not materialize.)

b) It is compatible with the present system, and with almost any system that may be required in the late 1980's and early 1990's.

c) A network with such a system is near minimum cost in the most likely traffic condition, and the penalty of choosing it is not greater than 3 or 4 million 1973 dollars in extreme traffic conditions.

TABLE 4.2

Satellite System Choices For the 1980-87 Interval

Traffic Forecast	Satellite System	
	Anik-Type	RCA-Type
Minimum	One Anik Plus Backup	One RCA-type plus backup Extra $2.5 M/Year
Preferred	Two Aniks plus backup	One RCA-type plus backup
	Very Little Cost Differential	
Maximum	Two Aniks plus backup (with 11,000 voice circuits and TV distribution) Extra $4.4 M/Year	Two RCA-type plus backup (with 26,000 voice circuits and TV distribution)

4.4 DISTRIBUTION OF CBC REGIONAL TELEVISION PROGRAMS BY SATELLITE IN SOUTHERN CANADA

Throughout a large part of the study the distribution of CBC regional television programs in southern Canada was not considered to be a traffic requirement of the long-haul network, because different terrestrial systems are used for this traffic. However, because initial results of the study showed the satellite system to be a significant part of the long-haul network in the 1980's, the possibility of adding the capability to distribute southern CBC regional television programs to the satellite system was investigated.

System traffic requirements were determined from the DOC/CBC feasibility study of a broadcast satellite system. It was tentatively assumed that a regional program which is distributed to ten or more television stations would be distributed by satellite. The following meet that criterion:

English program in British Columbia with 14 stations

English program in Saskatchewan with 11 stations

English program in Manitoba with 19 stations

English program in Ontario with 27 stations

French program in Ontario with 10 stations

French program in Quebec with 29 stations

English program in the Maritimes with 11 stations

English program in Newfoundland with 12 stations

We did not determine whether distribution should be by satellite or a terrestrial system. Rather, we simply determined what technical features a cost-effective satellite system should have, and the marginal cost of adding that subsystem to the satellite system.

The satellite system was assumed to have the following characteristics:

1) Satellite antenna beams 1.2° x 2.4° for British Columbia, Ontario and Quebec, and 1.2° x 1.2° for the other five regions.

2) 16 foot receiving antennas, mounted on the roof of the television stations.

3) 4/6 GHz operating fequency in 1980-87, and either 4/6 GHz or 12/14 GHz in the later 1987-94 interval.

It was determined that:

a) 4/6 GHz can be used without exceeding the flux-density limitations in that band if digital transmission is used.

b) The costs of systems at 4/6 GHz and at 12/14 GHz are very similar, and so choice of frequency can be based on availability of equipment and alternate uses of the two frequency bands.

c) Use of lower cost receiving systems with transistor or tunnel diode preamps results in lower total system cost than if more expensive lower noise paramps were used.

d) With the above system characteristics 8 watt transponders are required at 4 GHz.

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e) The addition of the regional TV distribution capability to the satellite system with three in-orbit Anik-like satellites in the 1980-87 interval would increase the satellite weight in synchronous orbit from about 600 lb. to about 1075 lb.

f) The marginal annual cost to add the subsystem to the system with three in-orbit Aniks in 1980-87 is about 8.5 million 1973 dollars, or about $1.1 million per television signal. (It is this cost which should be compared with the cost of terrestrial transmission to determine a minimum-cost network.)

g) The cost of adding a regional TV distribution subsystem (with the same number of receiving stations) to the larger satellite system with three in-orbit RCA-type satellites is about $6.5 million (1973 dollars) per year. The reduced cost is because of the economy-of-scale of using a larger satellite.

4.5 COST-EFFECTIVE USE OF SATELLITE FREQUENCY BANDS

The four frequency bands that might be used to meet the services considered in the DLDCNS with a satellite system are the 180 MHz wide band at 2.5 GHz, the 500 MHz wide bands at 4/6 GHz and at 12/14 GHz, and the 2.5 GHz wide band at 18/30 GHz. The 2.5 GHz was not considered in detail because of its narrow bandwidth and because it was rejected in favour of 12/14 GHz in the DOC/CBC Broadcast Satellite Feasibility Study. The 18/30 GHz band was not considered in detail because the wide bandwidth that is available is not required to meet Canadian needs in the 1980's, and not likely in the 1990's, and because satellite development at 18/30 GHz is at a much earlier stage than at 4/6 GHz or 12/14 GHz. Serious consideration was given, however, to comparing the 4/6 GHz band with the 12/14 GHz band in the context of the existing Canadian network.

The advantages of the 4/6 GHz band are as follows:

1) There is negligible atmospheric attenuation of 4/6 GHz signals, in comparison with the attenuation of 12/14 GHz signals.

2) Many satellite ground stations have been constructed for the present Telesat 4/6 GHz system.

The advantages of a 12/14 GHz system are:

a) There is no flux-density limitation on radiation from the satellite at 12 GHz, while there is at 4 GHz.

b) A 12/14 GHz satellite system has priority over a new 12 GHz terrestrial system in any radio interference problem between the two types of system. This allows the construction of 12/14 GHz satellite ground stations in metropolitan areas without large backhaul systems.

c) Because the 12 GHz signal has a much smaller wavelength, satellite antenna systems are smaller, lighter, and less costly at 12 GHz. This is an important consideration when spot beams are used to achieve multiple use of the available spectrum.

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Comparison of the costs of various satellite system options showed that:

i) The 4/6 GHz band should be used for any service such as television distribution that requires Canada-wide coverage and does not have an excessive number of ground stations. In this situation the extra transponder power and weight at 12 GHz becomes quite important.

ii) The 12/14 GHz band should be used for a service such as high-capacity voice transmission if spot beams are required to increase the system capacity through multiple use of the spectrum.

iii) The costs of satellite systems for CBC regional TV distribution in southern Canada are quite similar at 4/6 GHz and at 12/14 GHz.

iv) If both satellite frequency bands are used, a composite satellite with subsystems at each frequency should be used. Use of separate satellites at the two different frequencies is much more expensive (about 10 million 1973 dollars extra per year to meet the 1990 preferred traffic forecast).

For minimum total network cost, the satellite system should evolve in the following way:

i) 4/6 GHz should be used exclusively until the required satellite capacity exceeds that of two operational (plus one in-orbit spare) satellites of the RCA type with Canada-wide coverage.

ii) When that capacity is exceeded, a higher frequency should be used for high capacity voice transmission through spot beams. 12/14 GHz should be used for that purpose unless it is required for services such as those being investigated with the CTS research satellite. If the latter is the case, 18/30 GHz should be used for high-capacity satellite voice transmission.

CHAPTER 5

5. CONCLUSIONS

Many technically feasible evolutions of the Canadian long-haul communications network in the 1980's were compared in this study by determining the relative costs of the different network options. Costs which were common to all possible network expansions were not taken into account, because the objective of the study was to determine the most cost-effective network expansion and the extra costs associated with other feasible expansions, rather than to estimate the absolute cost of the total network. Thus the cost figures given here are not suitable for use as a basis for rate evaluations.

Of the many technically feasible networks considered, two distinct types of network evolution emerged as being significant. One of these is the

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minimum-total-cost network, which would be developed by a hypothetical, single carrier operating both terrestrial and satellite facilities and providing all Canadian domestic transmission requirements. The other is the network which will likely emerge if there is no change in the institutional arrangements between the common carriers in Canada in the next decade. The major difference between these two network expansions is that in the latter there would not be a significant amount of high-capacity voice traffic through the satellite in southern Canada until the two TCTS 4 GHz microwave systems, and their augmentations at 6 GHz and 8 GHz, are fully utilized. This is not likely to occur until the mid 1990's. In contrast, in the minimum-total-cost network significant amounts of voice traffic is carried by satellite. By the late 1980's ten to twenty thousand voice circuits would be routed through the satellite, and this amount would be limited by the network survivability requirements rather than by the relative costs of augmenting the satellite or the terrestrial systems. The present value (in 1980) of the minimum-cost network is about ten million 1973 dollars less than the alternate network.

In both of the above networks the northern thin-route voice requirements to established communities and nationwide television distribution requirements in both northern and southern Canada would be met with a 4/6 GHz satellite system with a Canada-wide beam. By using presently available cost-effective techniques to provide source encoding, multiple access, and demand assignment, these thin-route voice and television distribution requirements would be met with an Anik-like satellite with in-orbit backup in 1980-87, and an RCA-type satellite with in-orbit backup in the later 1987-94 interval.

In the minimum-total-cost network the satellite systems mentioned above would be augmented with a third Anik-like satellite in 1980-87, and a third RCA-type satellite in the 1987-94 interval. The extra satellite system capacity would be used to carry medium-capacity and high-capacity voice traffic principally between Vancouver or Edmonton in the west and Toronto or Montreal in the east. Present Telesat ground stations in southern Canada would be augmented to be able to transmit and receive from two satellites simultaneously. Given the existing situation that 4/6 GHz satellite ground stations and the infrastructure of the backhaul systems are already installed, it is not cost-effective to use the 12/14 GHz band until the 4/6 GHz satellite system with Canada-wide beam is saturated. This is not expected to occur until the mid 1990's.

The terrestrial networks will likely expand in much the same way whether or not the satellite system carries significant amounts of voice traffic, but the timing of this expansion would be significantly different. The 6 GHz CN/CP system will likely be adequate for CN/CP's requirements throughout the 1980's in either case, except for possible expansion in the Toronto-Montreal area, and adequate throughout the 1990's in a minimum-cost network. Expansion of the TCTS terrestrial network will be by augmentation of the existing 4 GHz systems, first with a 8 GHz digital system, and perhaps later with a 6 GHz digital system and then by conversion of the 4 GHz system to a digital one. Such expansion is expected to meet TCTS's needs until the turn of the century in a minimum-cost network, and well into the 1990's without voice traffic by satellite.

It is expected that the above two scenarios would become one in the mid 1990's. At that time the satellite system is expected to include three composite satellites in orbit. Thin-route voice traffic, national television distribution, and perhaps regional CBC television distribution would be with a 4/6 GHz satellite subsystem. 12/14 GHz, or perhaps 18/30 GHz would be used in a spot-beam satellite subsystem for high-capacity voice transmission. The reason for the merging of the two network scenarios is that it would be cost-effective from CNCP's and TCTS's viewpoint to lease satellite capacity from Telesat at that time rather than construct completely independent new trans-Canada systems. Thus the difference in the two network scenarios is a temporary one, lasting about fifteen years, at a total cost of about 10 million 1973 dollars.

Because of the significant difference between the above two network scenarios, the reasons for the difference should be clarified. Apart from short term switching problems through satellite systems and excess terrestrial transmission capacity, which will become insignificant in the 1980's, TCTS will likely be reluctant to use satellites in the 1980's for the following reasons:

1) The *rate* which Telesat would charge TCTS is significantly more than the *marginal cost* to TCTS to increase the capacity of their terrestrial system instead. (In constrast, Telesat's *marginal cost* to increase the size of the satellite system is significantly less than TCTS's terrestrial cost.)

2) Neither the satellite nor the ground stations are included in the rate base of the TCTS member companies.

3) The prairie carriers, in particular, benefit from revenues from traffic which passes through their territories but is neither originated nor terminated there. If it was routed through the satellite system they would not have this revenue.

Reasons (1) and (2) also apply to CNCP.

If the network is to evolve in the most cost-effective manner from the viewpoint of the nation as a whole, these rate problems will have to be resolved.

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8. ABSTRACT: The most cost-effective satellite systems 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 continue 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 million 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 terrestrial 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 1.2 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.

9. CITATION:

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