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Topological Analysis of CANUNET

BY

John deMercado
René Guindon
John Da Silva
Michel Kadoch

Terrestrial Planning Branch
Department of Communications
OTTAWA

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To: Chairman, CANUNET Advisory Committee

This is the final report of the Communication Studies Group for the Canadian Universities Computer Network (CANUNET) study. It was prepared under the direction of Mr. R. Guindon of my Branch who served as the Chairman of this group.

The report is divided into three parts. Part I gives the results of the Topological Analysis of several possible network realizations for CANUNET based on hybrid (ANIK satellite - terrestrial) communication facilities.

Part II contains the main results (revised) that were given in our first report "Topological Analysis and Design of CANUNET"- January 1972.

Part III gives various cost comparisons of the networks of Parts I and II.

Dr. John deMercado
Director,
Terrestrial Planning Br.

Acknowledgements

The authors wish to acknowledge the participation of the following people who were members of the Communication Study Group for the CANUNET project. The authors, however, assume full responsibility for the content of this report.

List of Members:

J. de Mercado	Department of Communications
R. Guindon	" " "
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M. Kadoch	" " "
J. Fortier	University of Quebec
A. Curran	Bell/Northern Research
E. Newhall	University of Toronto

Table of Contents

APPENDICES

Summary

This report presents the topological analysis of various possible networks for CANUNET. Several Network Topologies based on the use of the ANIK satellite with terrestrial facilities are analyzed in Part I. In Part II possible network topologies for CANUNET based on the use of terrestrial facilities only are analyzed.

Part III gives various cost comparison figures for the networks of Parts I and II.

The computer programs used to simulate these various topologies were developed within the Department, are completely conversational, and are located on its Sigma-7 computer at Shirley's Bay in Ottawa.

PART I

HYBRID NETWORKS FOR CANUNET

Introduction

In this part, results are presented of the simulations that were made of various 10, 14 and 18 node network topologies using (hybrid) satellite - terrestrial communication facilities for CANUNET. Performance graphs are given of total input data rate versus average message delays for average message lengths of 640 bits for each of these topologies having the communication line speeds as noted.

Chapter I contains a discussion of the hybrid network configurations, as well as the figures of the actual networks topologies that were analyzed and the corresponding performance graphs.

Chapter II contains the complete simulation of a 15 node hybrid network. Such simulations were conducted for all of the hybrid networks, but have not been, in the interest of brevity, reproduced here.

Chapter III contains a detailed, but preliminary report from Telesat Corporation on the application of the ANIK satellite's facilities to CANUNET. It should be noted, as per their letter, that Telesat is prepared to undertake more detailed engineering studies in support of using the ANIK satellite to realize CANUNET.

CHAPTER I

Network Model Considerations

The topologies considered here in Part I are derived from the joint use of the ANIK satellite and Common Carrier terrestrial communication facilities. This report contains an analysis of several possible 10, 14 and 18 node hybrid (satellite-terrestrial) networks for CANUNET.

The exact queuing model for the hybrid system should have been M/M/n *) for the satellite system and M/M/1 for the Node Control Unit in the terrestrial network. This is because in the satellite system, each ground station transmits at a particular assigned frequency which can be received by all other ground stations; thus the satellite simultaneously serves several frequencies depending on the number of carriers or stations.(see for example in Fig. 5 of the Telesat report in Chapter III).

In order to be able to simulate the hybrid network, the simulation program used was based on the M/M/1 queue model for both the satellite as well as the terrestrial facility. Therefore, the results obtained were not valid for all representations of the system, but were rather a representation of the worst case situation. If M/M/n theory were used, it could be expected that the average message delay in the network would be less than that given in this report.

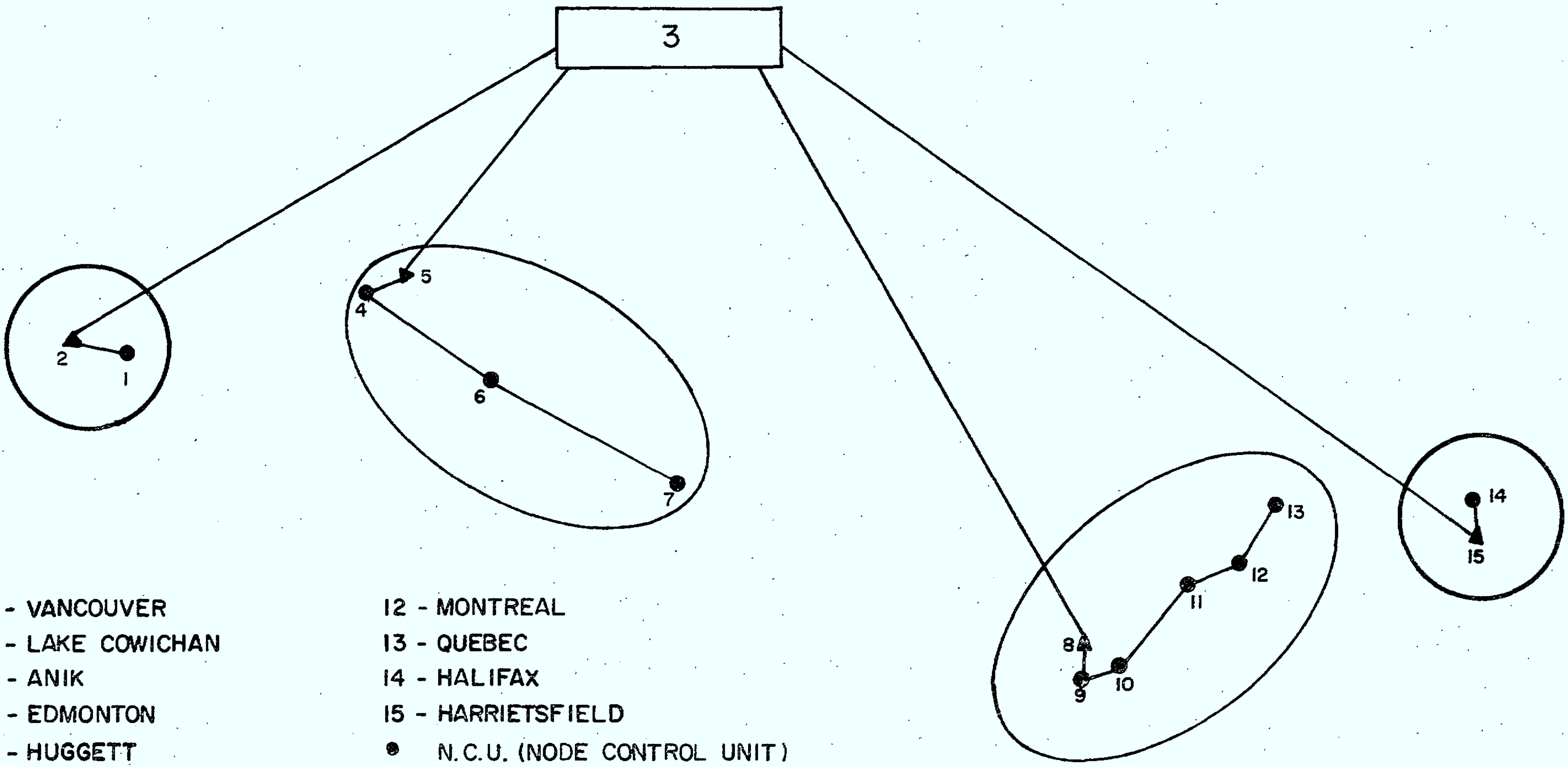
---

*) where n in this case is the number of carriers in the satellite (i.e. the number of servers).

Network Topologies and Performance Graphs

Following is a summary of results of the 10, 14 and 18 node hybrid option for CANUNET. It includes for each network its topology and graphs of "Total Average Delay" versus "Total Input Data Rate".

NOD 10 SAT 4
TOPOLOGY #1

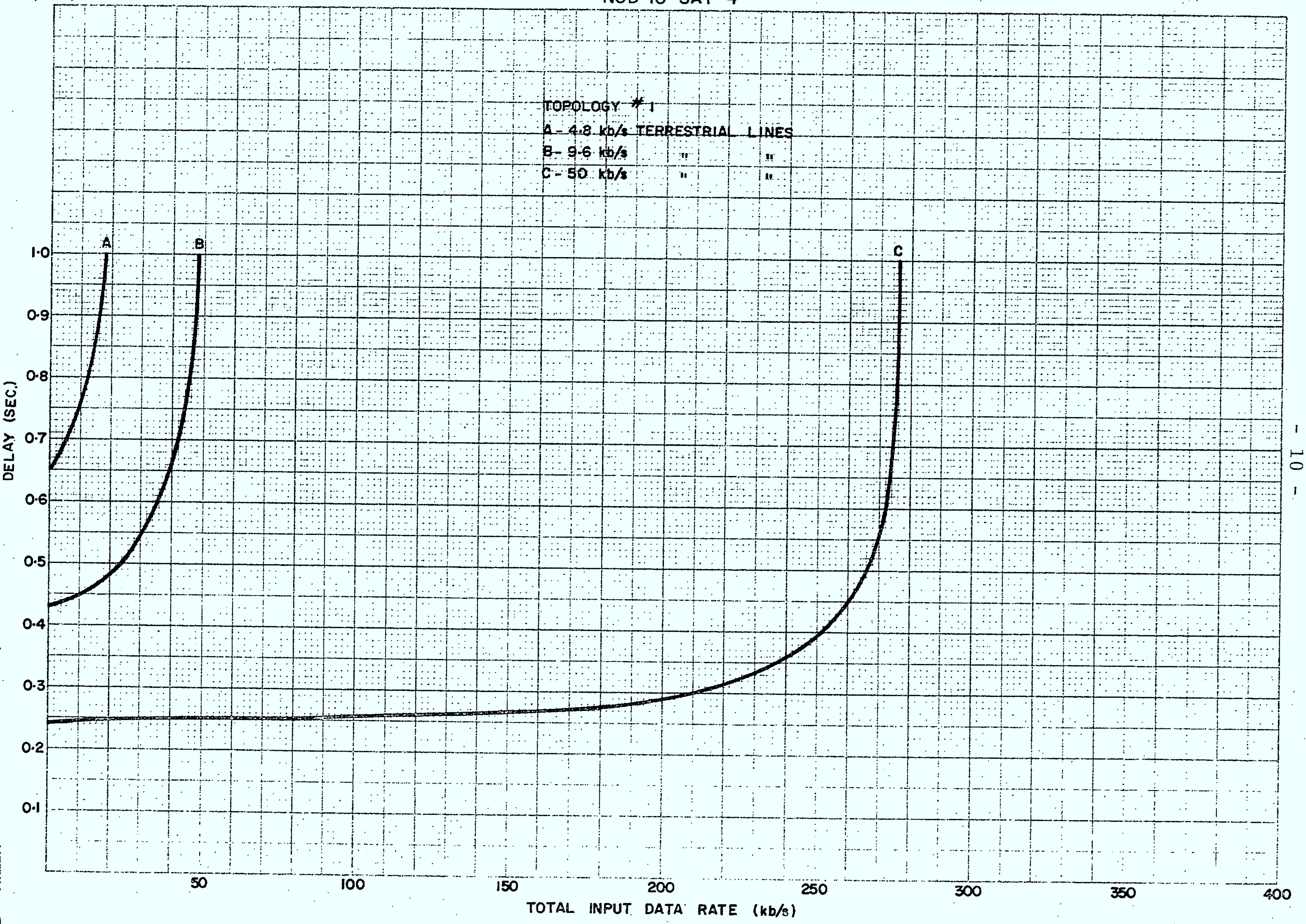


1 - VANCOUVER
2 - LAKE COWICHAN
3 - ANIK
4 - EDMONTON
5 - HUGGETT
6 - SASKATOON
7 - WINNIPEG
8 - ALLAN PARK
9 - WATERLOO
10 - TORONTO
11 - OTTAWA
12 - MONTREAL
13 - QUEBEC
14 - HALIFAX
15 - HARRIETSFIELD

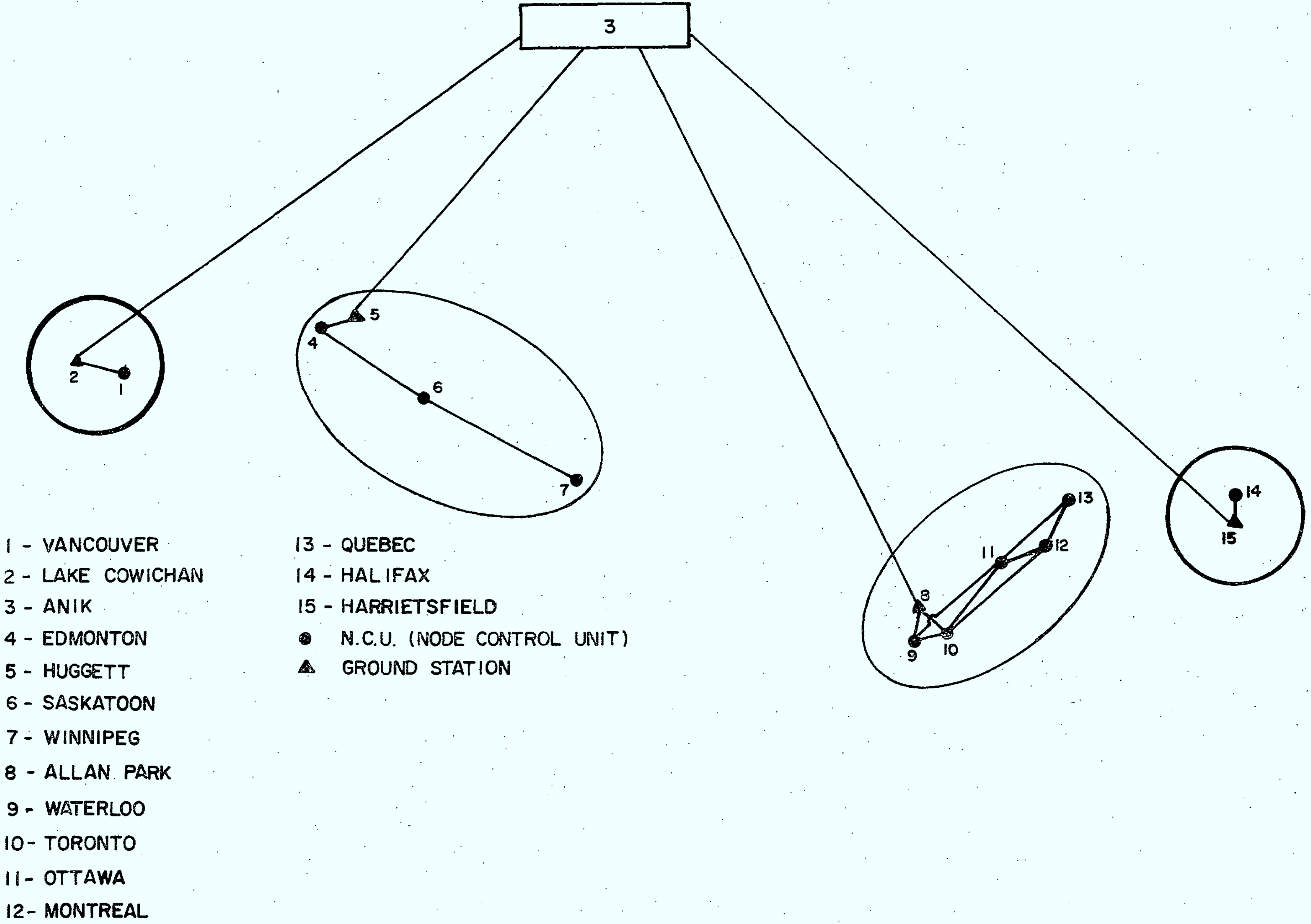
● N.C.U. (NODE CONTROL UNIT)
▲ GROUND STATION

K&E 10 TO 1/2 INCH 46 1327
KEUFFEL & ESSER CO.

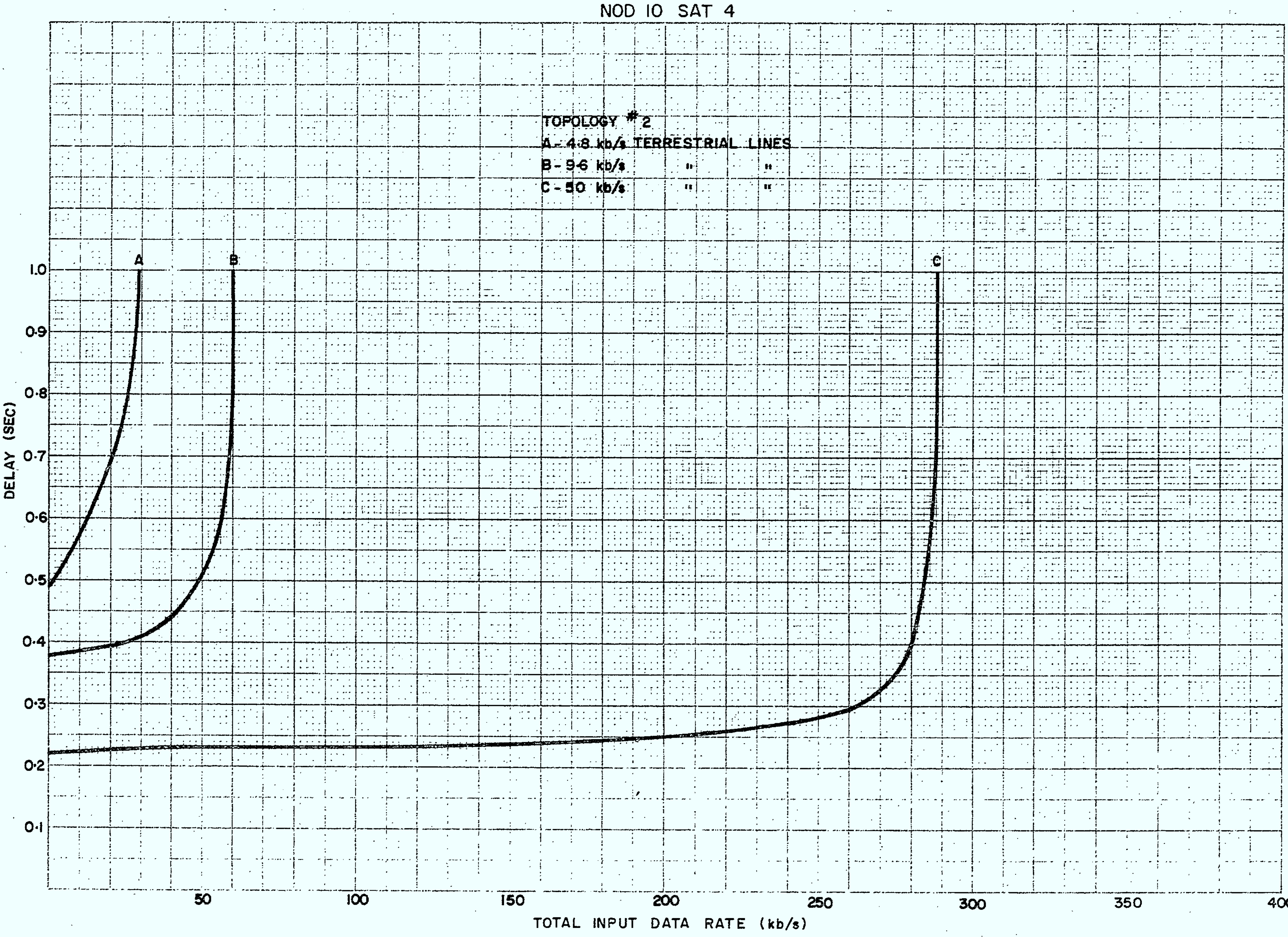
NOD 10 SAT 4



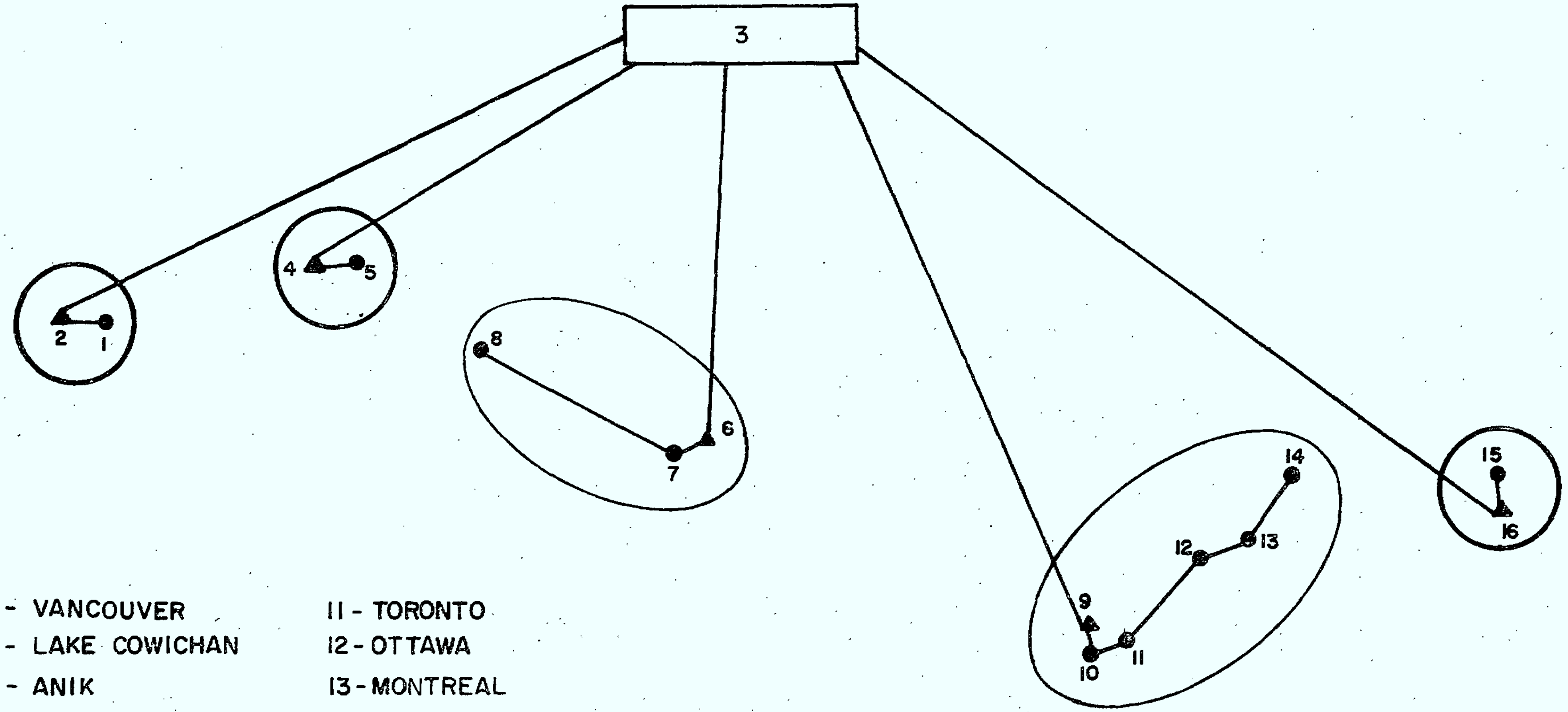
NOD 10 SAT 4
TOPOLOGY # 2



46 1327


NOD 10 SAT 4
TOPOLOGY # 2
A - 4·8 kb/s TERRESTRIAL LINES
B - 9·6 kb/s " "
C - 50 kb/s " "
A
B
C
DELAY (SEC)
1.0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
50
100
150
200
250
300
350
400
TOTAL INPUT DATA RATE (kb/s)

NOD 10 SAT 5 (ALLAN PARK)
TOPOLOGY #1



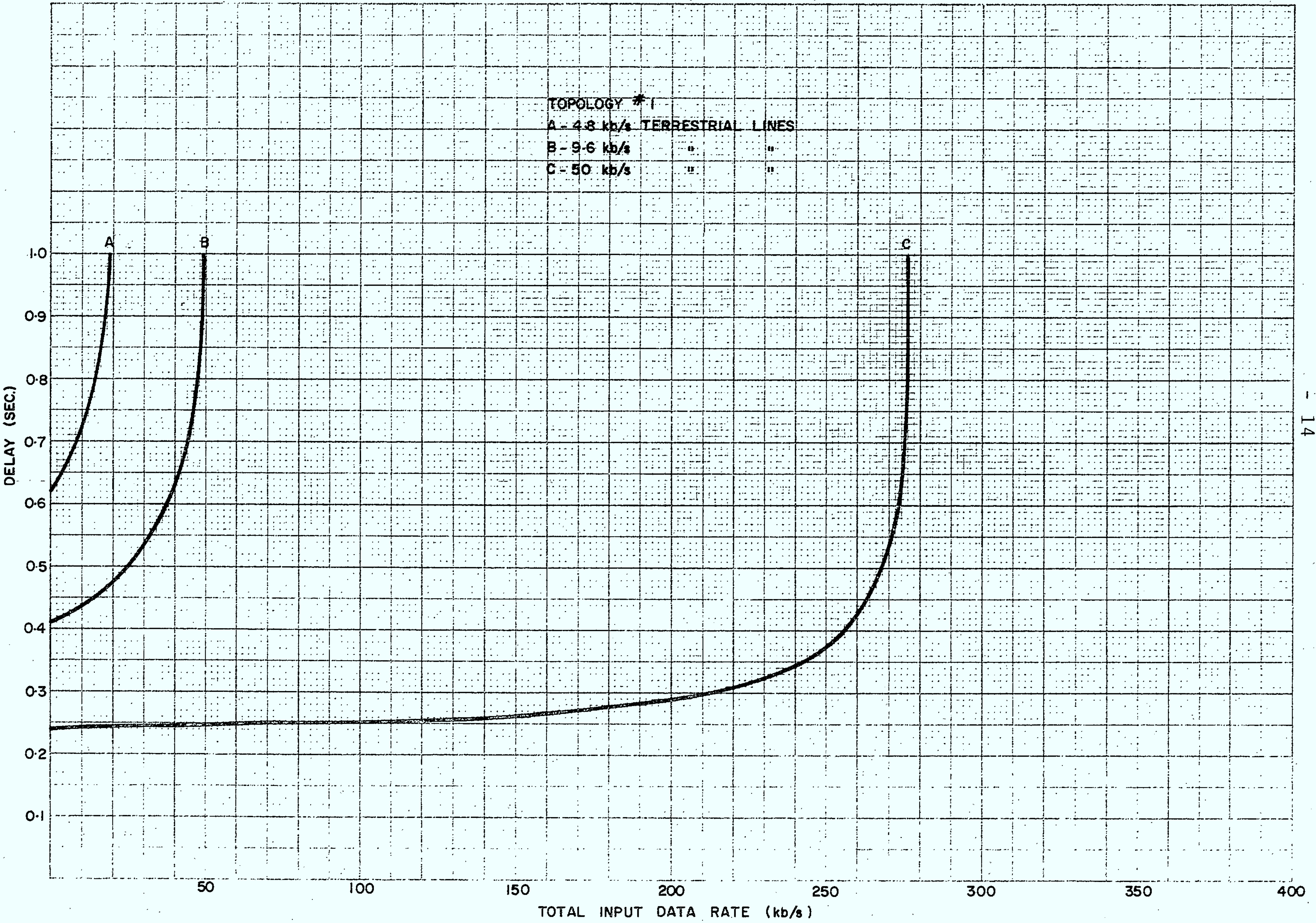
1 - VANCOUVER
2 - LAKE COWICHAN
3 - ANIK
4 - HUGGETT
5 - EDMONTON
6 - GRAND BEACH
7 - WINNIPEG
8 - SASKATOON
9 - ALLAN PARK
10 - WATERLOO
11 - TORONTO
12 - OTTAWA
13 - MONTREAL
14 - QUEBEC
15 - HALIFAX
16 - HARRIETSFIELD

● N. C.U. (NODE CONTROL UNIT)

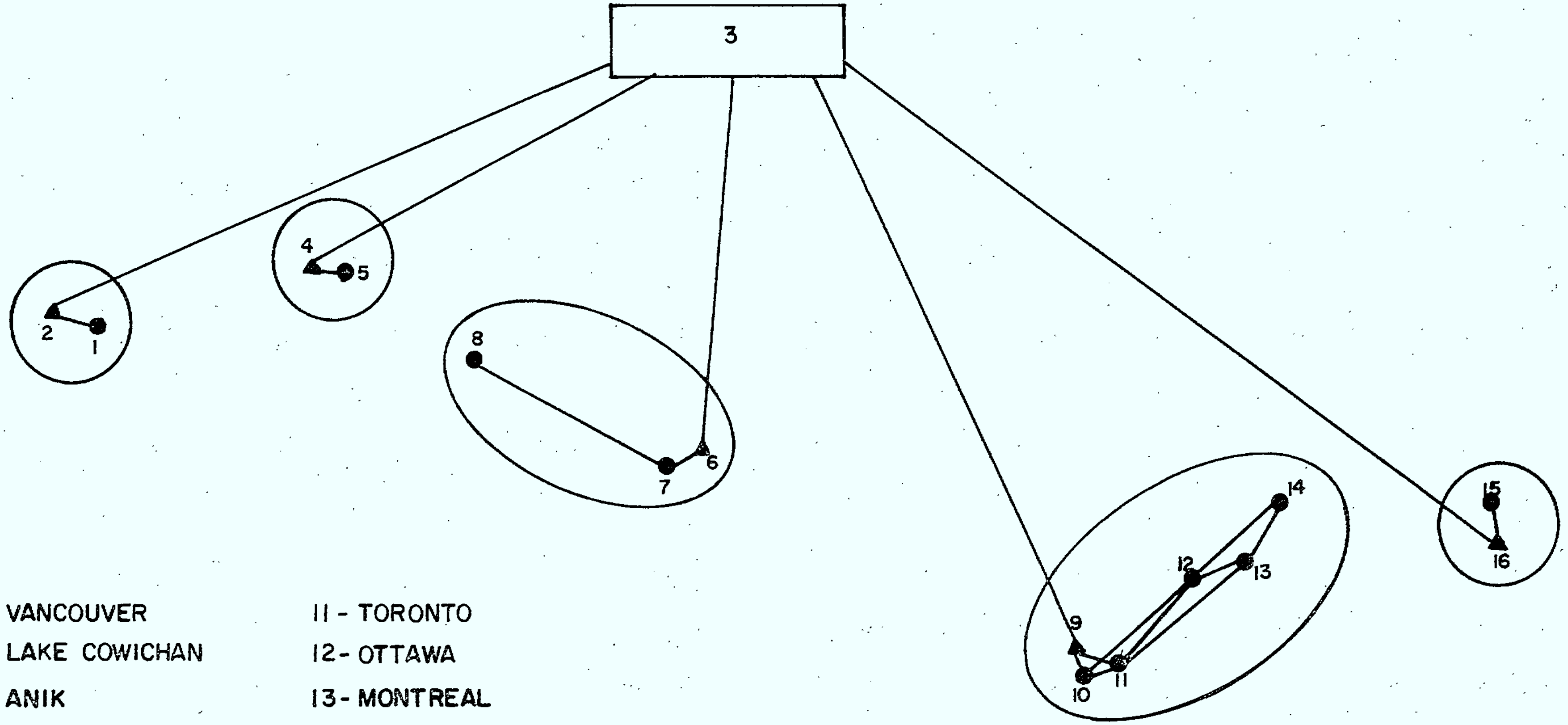
▲ GROUND STATION

K&E 10 X 10 TO ½ INCH 46 1327
KEUFFEL & ESSER CO.

NOD 10 SAT 5 (ALLAN PARK)



NOD 10 SAT 5 (ALLAN PARK)
TOPOLOGY # 2



1 - VANCOUVER
2 - LAKE COWICHAN
3 - ANIK
4 - HUGGETT
5 - EDMONTON
6 - GRAND BEACH
7 - WINNIPEG
8 - SASKATOON
9 - ALLAN PARK
10 - WATERLOO

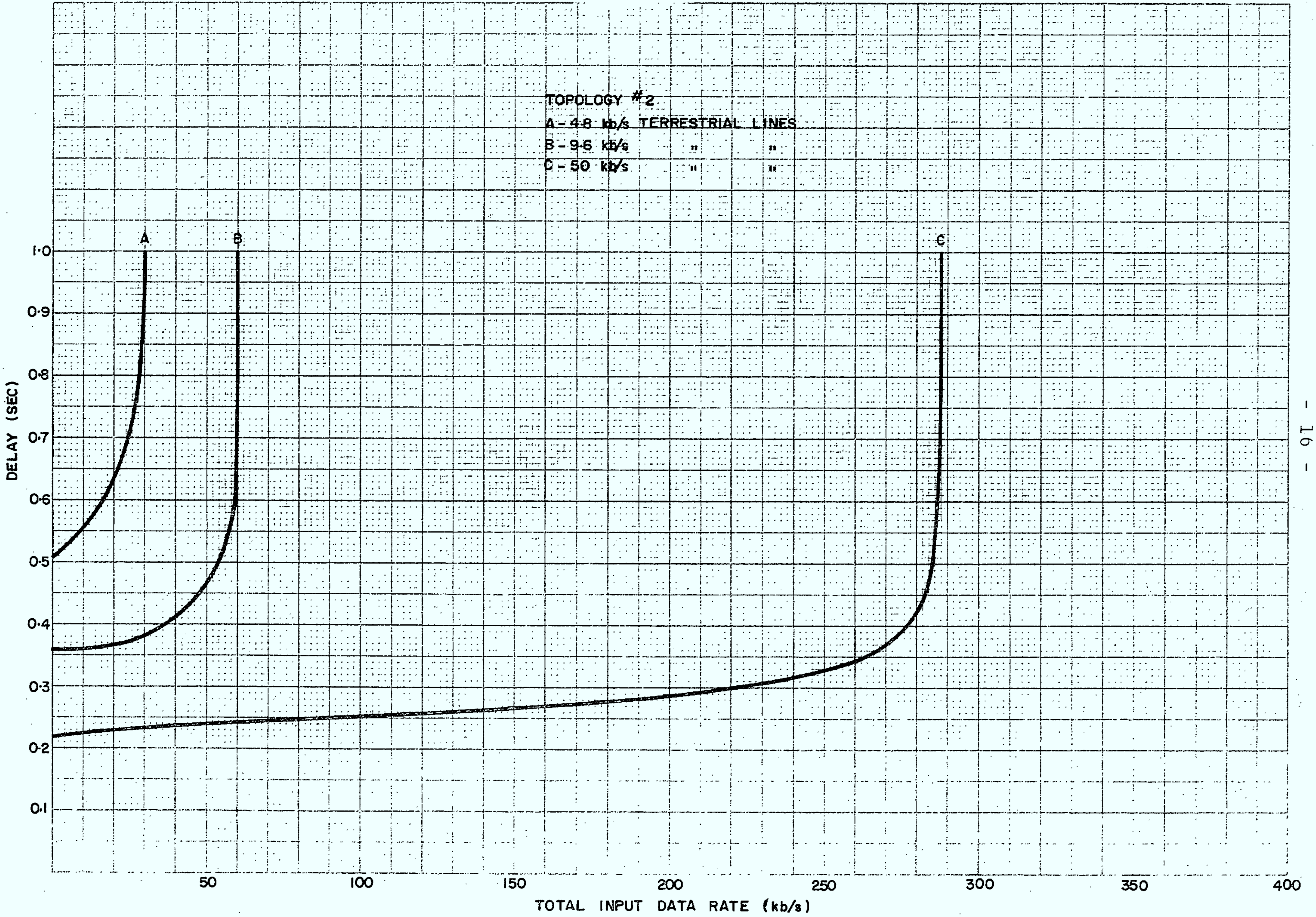
11 - TORONTO
12 - OTTAWA
13 - MONTREAL
14 - QUEBEC
15 - HALIFAX
16 - HARRIETSFIELD

⊗ N. C. U. (NODE CONTROL UNIT)

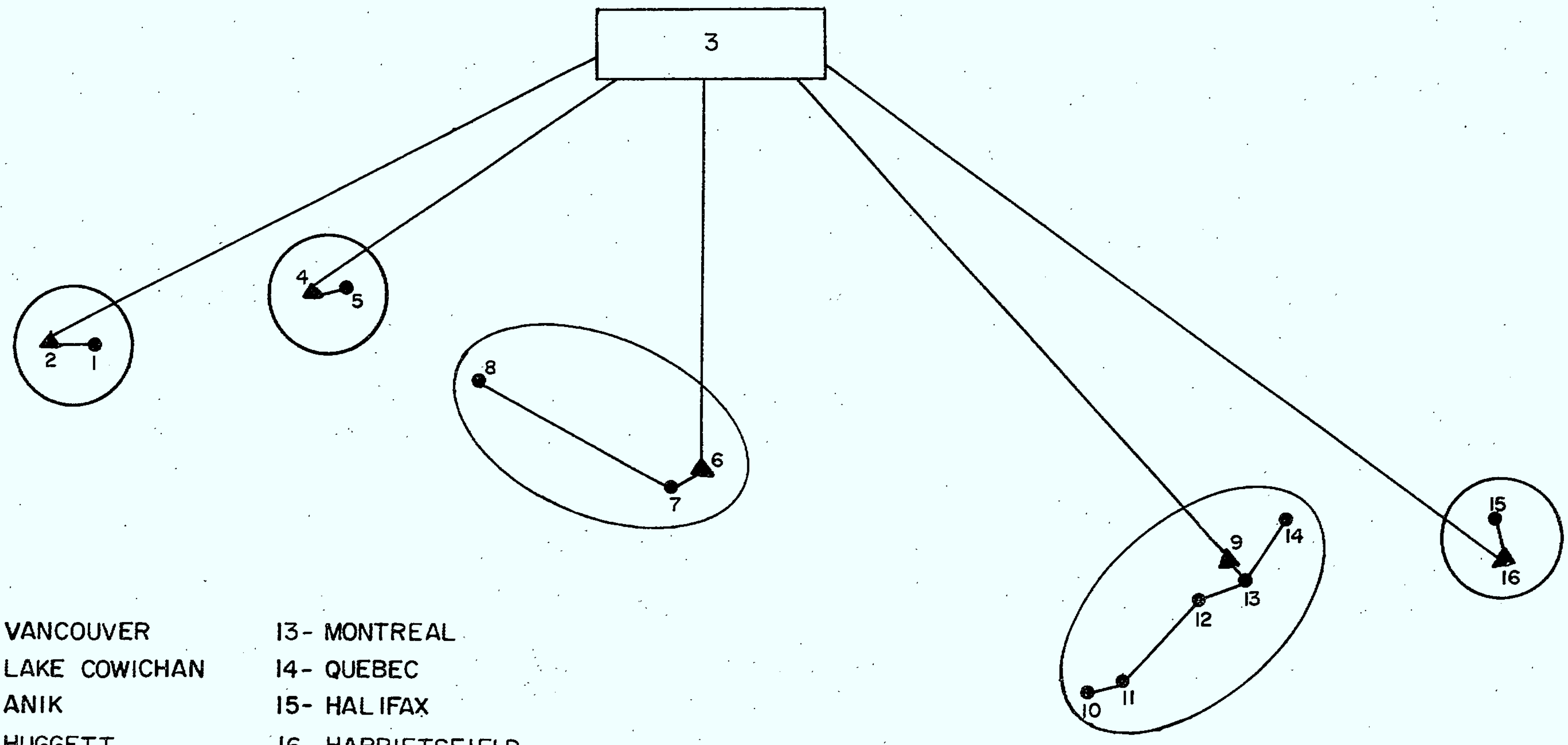
▲ GROUND STATION

K+E 10 X 10 TO ½ INCH 46 1327
KEUFFEL & ESSER CO.

NOD 10 SAT 5 (ALLAN PARK)



NOD 10 SAT 5 (RIVIERE ROUGE)

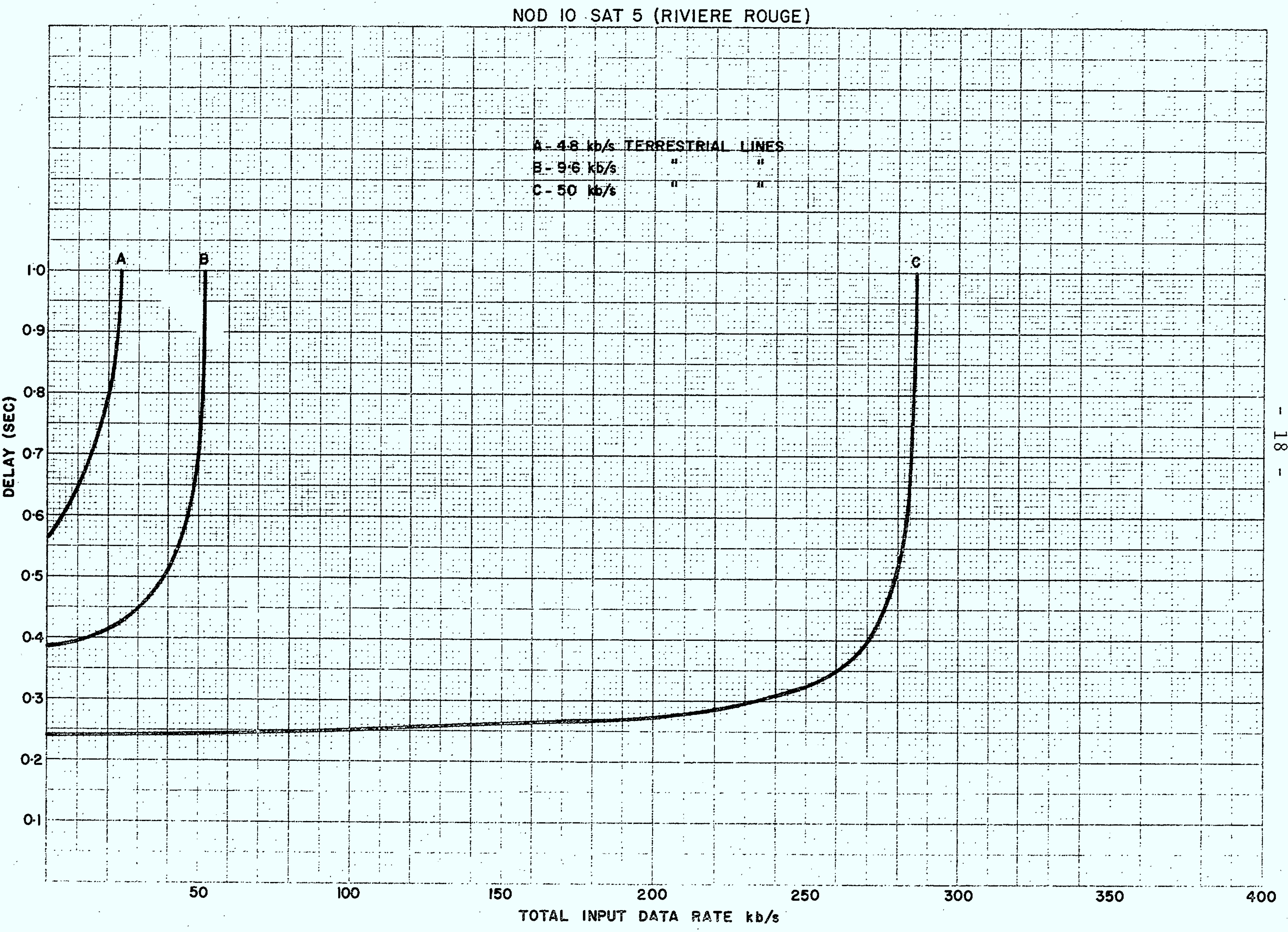


1- VANCOUVER
2- LAKE COWICHAN
3- ANIK
4- HUGGETT
5- EDMONTON
6- GRAND BEACH
7- WINNIPEG
8- SASKATOON
9- RIVIERE ROUGE
10- WATERLOO
11- TORONTO
12- OTTAWA
13- MONTREAL
14- QUEBEC
15- HALIFAX
16- HARRIETSFIELD

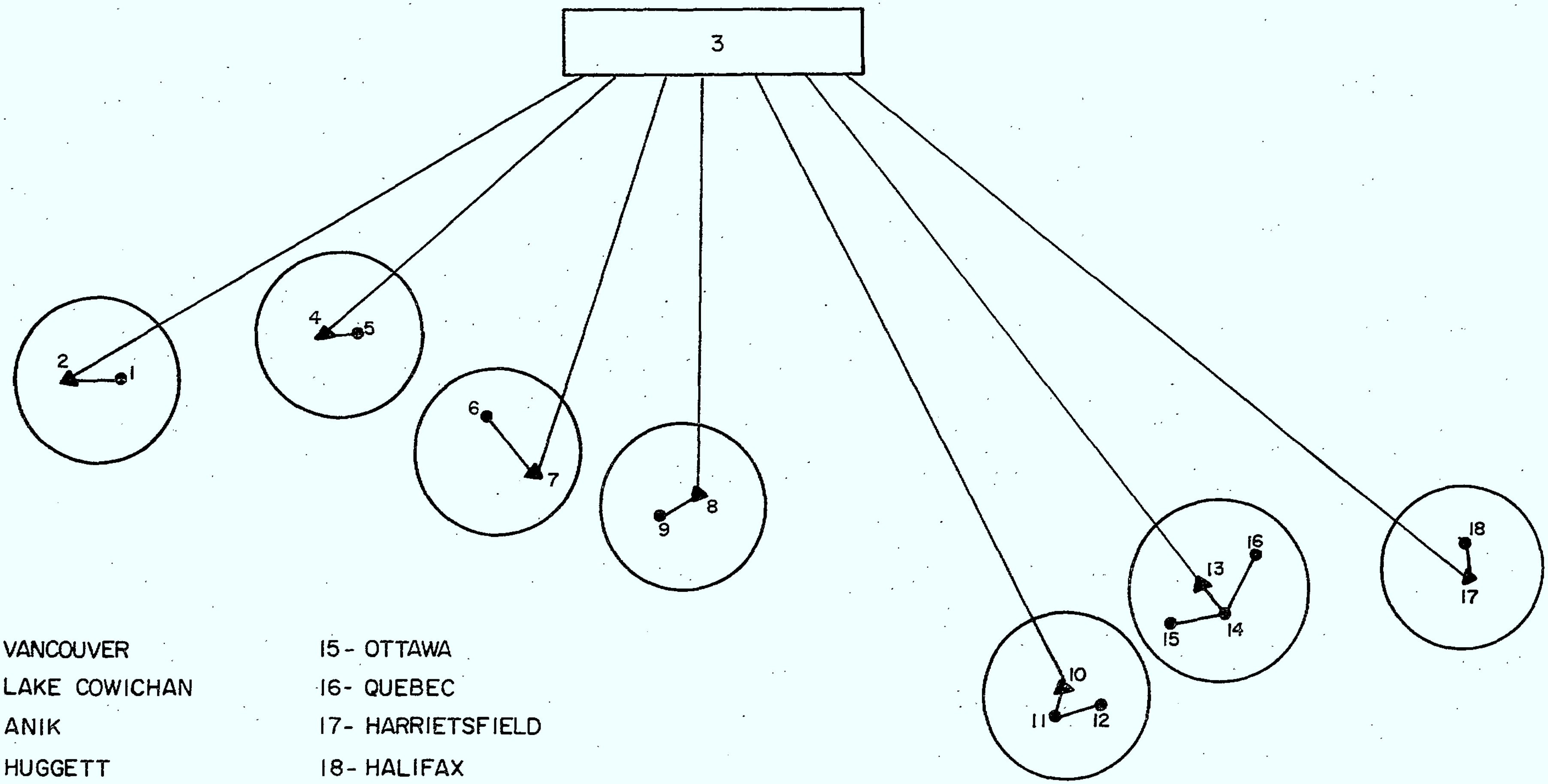
● N.C.U. (NODE CONTROL UNIT)

▲ GROUND STATION

K&E 10 X 10 TO ½ INCH 46 1327
ALBANENE
KEUFFEL & ESSER CO.



NOD 10 SAT 7



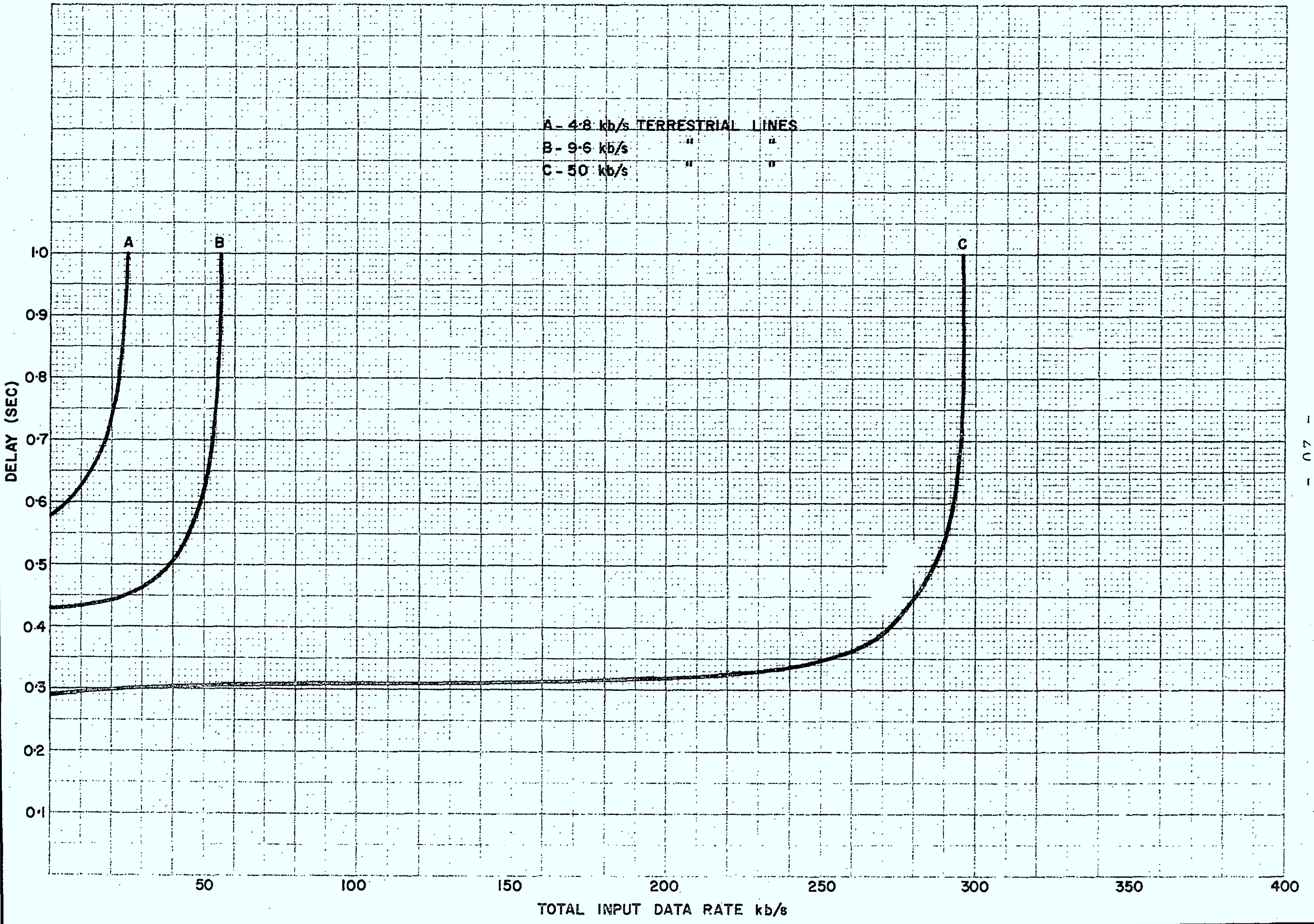
1- VANCOUVER
2- LAKE COWICHAN
3- ANIK
4- HUGGETT
5- COMONTON
6- SASKATOON
7- QU'APPELLE
8- GRAND BEACH
9- WINNIPEG
10- ALLAN PARK
11- WATERLOO
12- TORONTO
13- RIVIERE ROUGE
14- MONTREAL
15- OTTAWA
16- QUEBEC
17- HARRIETSFIELD
18- HALIFAX

● N.C.U. (NODE CONTROL UNIT)

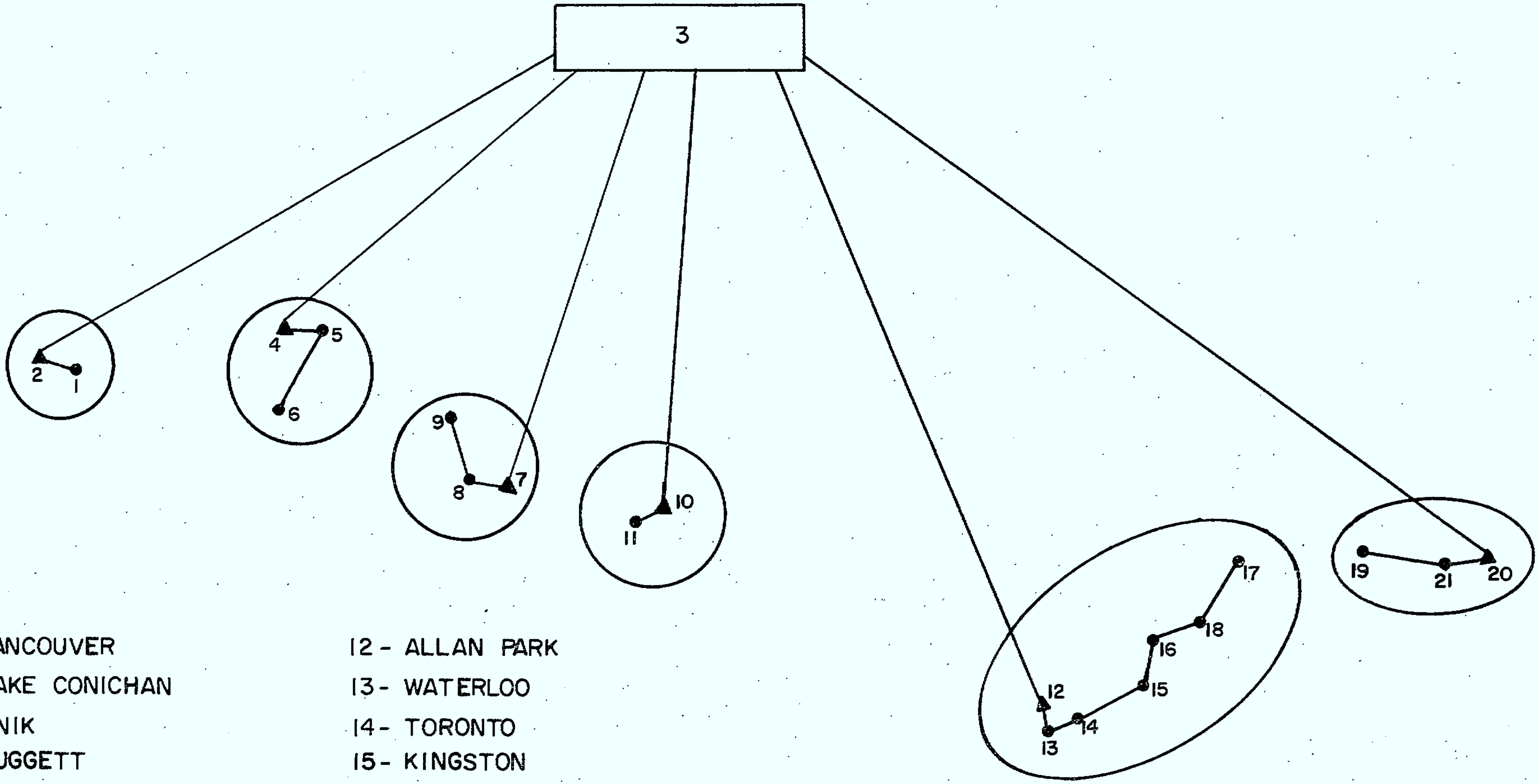
▲ GROUND SYSTEM

10 X 10 TO ½ INCH 46 1327

NOD 10 SAT 7



NOD 14 SAT 6



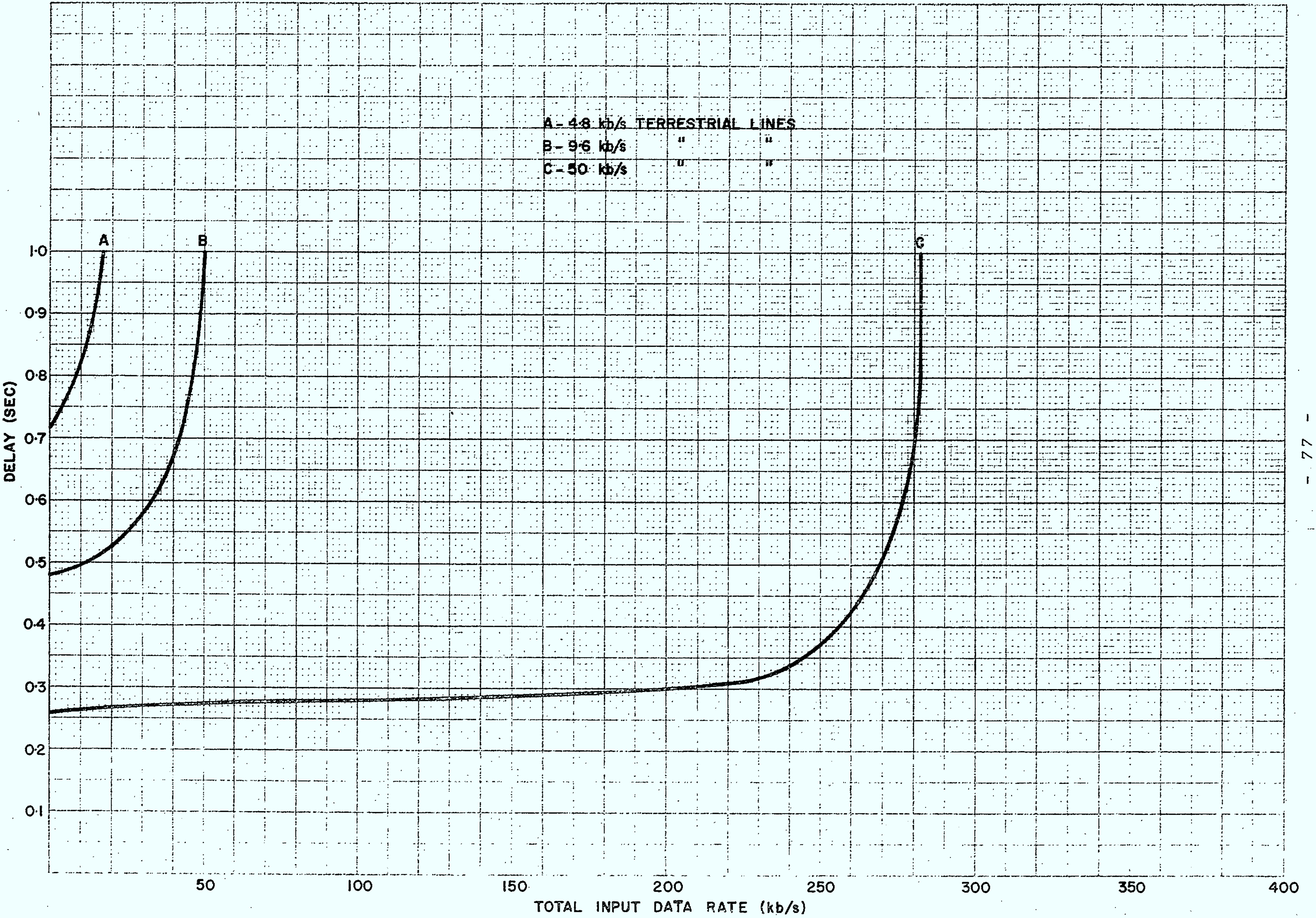
1 - VANCOUVER
2 - LAKE CONICHAN
3 - ANIK
4 - HUGGETT
5 - EDMONTON
6 - CALGARY
7 - QU'APPELLE
8 - REGINA
9 - SASKATOON
10 - GRAND BEACH
11 - WINNIPEG

12 - ALLAN PARK
13 - WATERLOO
14 - TORONTO
15 - KINGSTON
16 - OTTAWA
17 - QUEBEC
18 - MONTREAL
19 - FREDERICTON
20 - HARRIETSFIELD
21 - HALIFAX

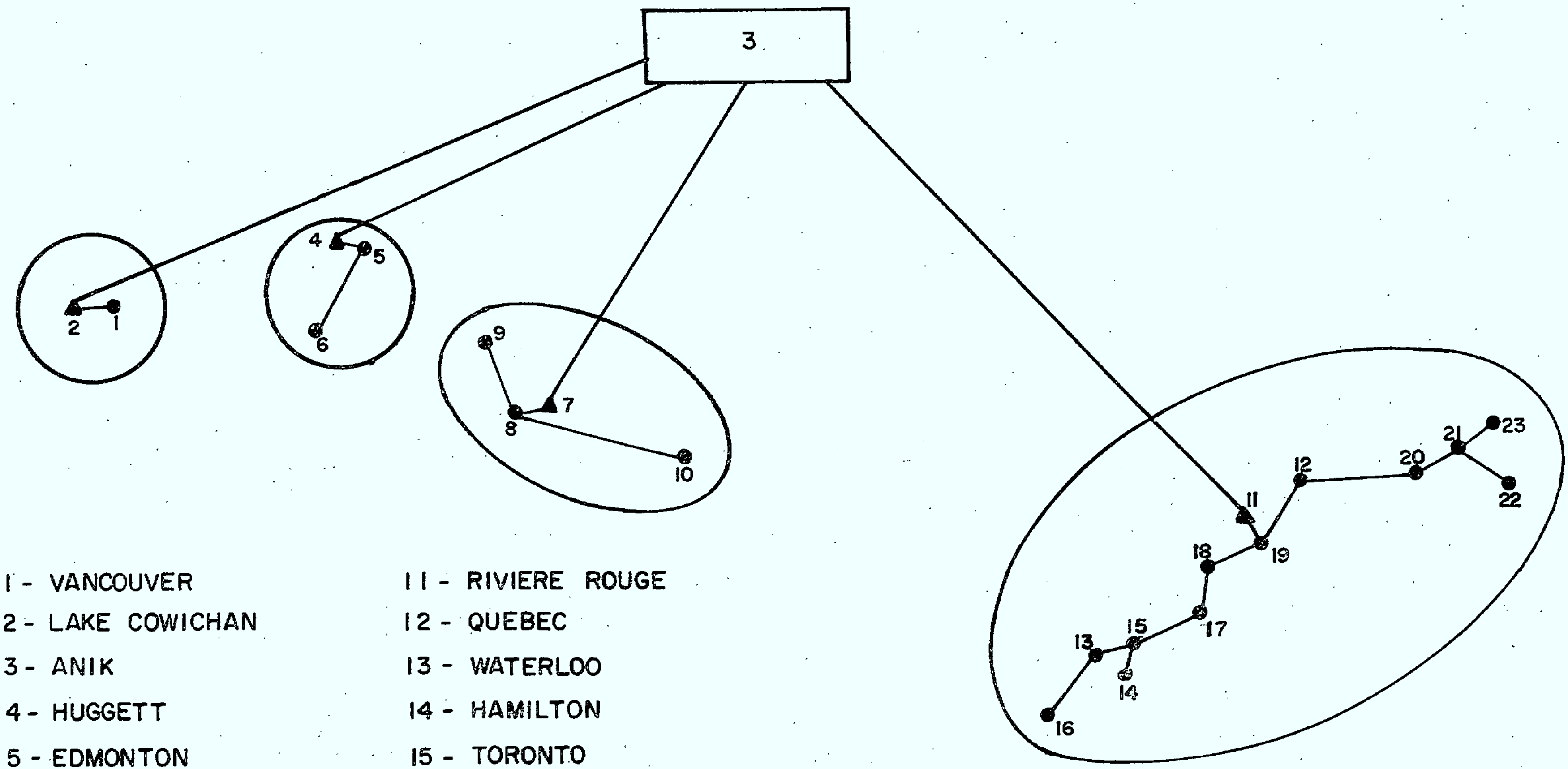
● N. C. U. (NODE CONTROL UNIT)
▲ GROUND STATION

K&E 10 X 10 TO ½ INCH 46 1327
KEUFFEL & ESSER CO.

NOD 14 SAT 6



NOD 18 SAT 4

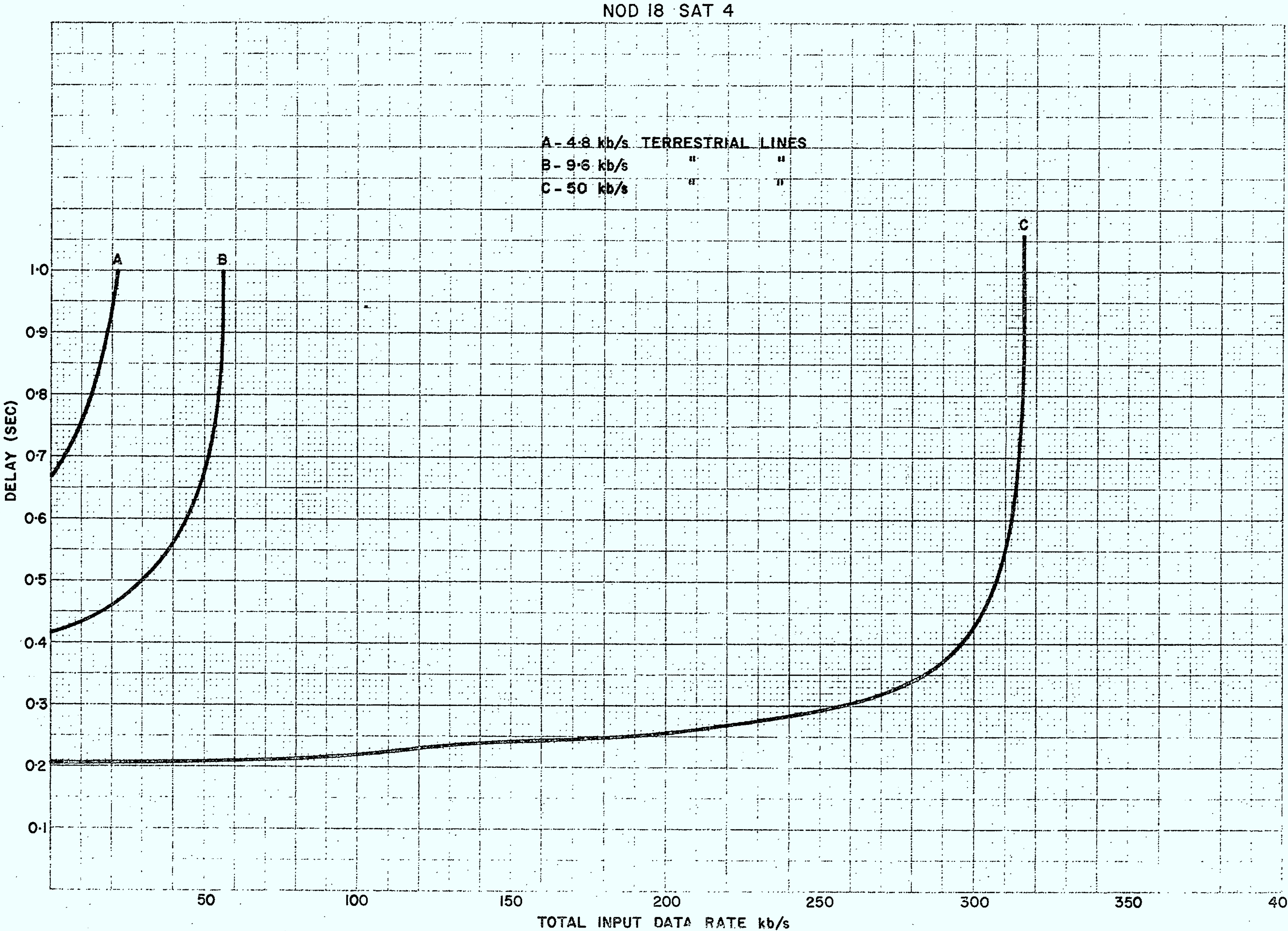


1 - VANCOUVER
2 - LAKE COWICHAN
3 - ANIK
4 - HUGGETT
5 - EDMONTON
6 - CALGARY
7 - QU'APPELLE
8 - REGINA
9 - SASKATOON
10 - WINNIPEG

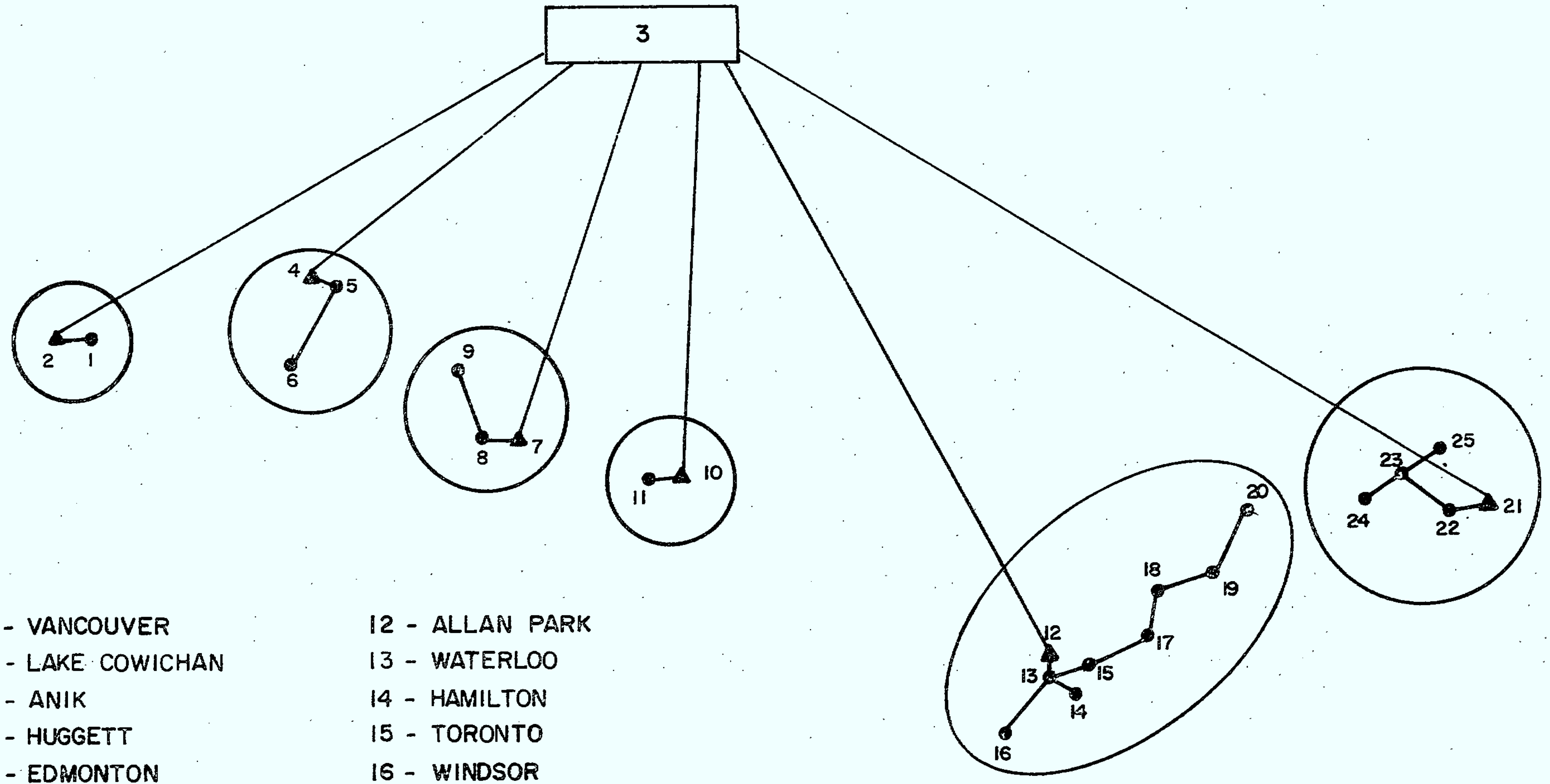
11 - RIVIERE ROUGE
12 - QUEBEC
13 - WATERLOO
14 - HAMILTON
15 - TORONTO
16 - WINDSOR
17 - KINGSTON
18 - OTTAWA
19 - MONTREAL
20 - FREDERICTON

22 - HALIFAX
23 - CHARLOTTETOWN

● N. C. U. (NODE CONTROL UNIT)
▲ GROUND STATION


NOD 18 SAT 4
A - 4·8 kb/s TERRESTRIAL LINES
B - 9·6 kb/s " "
C - 50 kb/s " "
A
B
C
DELAY (SEC)
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
50
100
150
200
250
300
350
400
TOTAL INPUT DATA RATE kb/s

NOD 18 SAT 6



1 - VANCOUVER
2 - LAKE COWICHAN
3 - ANIK
4 - HUGGETT
5 - EDMONTON
6 - CALGARY
7 - QU'APPELLE
8 - REGINA
9 - SASKATOON
10 - GRAND BEACH
11 - WINNIPEG

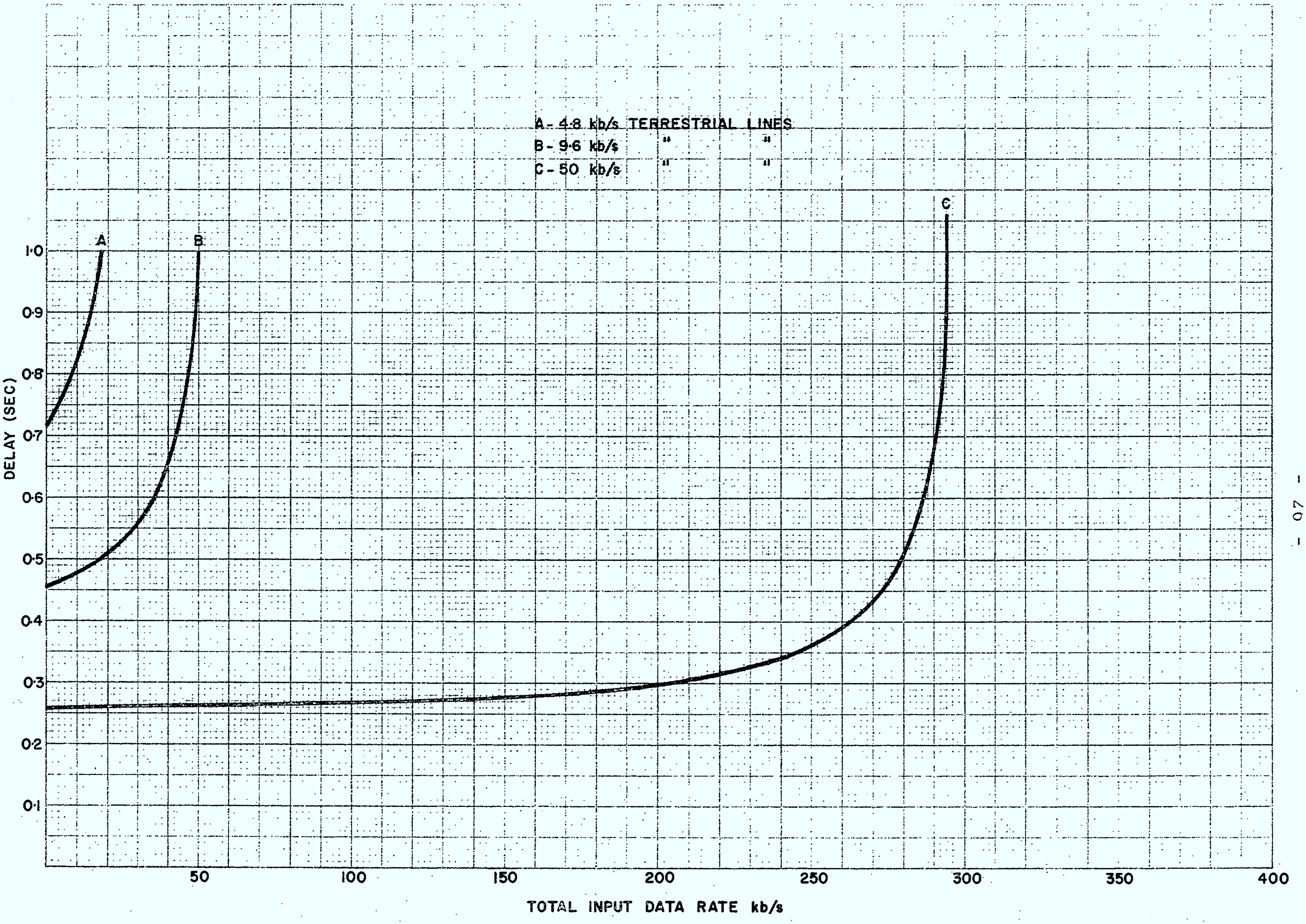
12 - ALLAN PARK
13 - WATERLOO
14 - HAMILTON
15 - TORONTO
16 - WINDSOR
17 - KINGSTON
18 - OTTAWA
19 - MONTREAL
20 - QUEBEC
21 - HARRIETSFIELD
23 - HALIFAX

23 - MONCTON
24 - FREDERICTON
25 - CHARLOTTETOWN

● N.C.U. (NODE CONTROL UNIT)

▲ GROUND STATION

NOD 18 SAT 6



A - 4·8 kb/s TERRESTRIAL LINES
B - 9·6 kb/s " "
C - 50 kb/s " "
A
B
C
DELAY (SEC)
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
50
100
150
200
250
300
350
400
TOTAL INPUT DATA RATE kb/s

CHAPTER II

Detailed Simulation of a 10 Node Hybrid Network

The following is a description of the simulation for Network NOD 10 SAT 4 using topology #2*)and 50.0 kb/s lines.

Average packet length = 640 bits

Average of (packet and acknowledgement) = 400 bits.

It contains;

$[C]$ = Branch Capacity Matrix (bits/sec)

$[T]$ = Traffic Matrix (bits/sec)

$[\lambda]$ = Matrix of the Average # of Messages/sec

$[\rho]$ = Network Utilization Matrix

$[A.D]$ = Average Delay Matrix in sec/message

$[R]$ = Shortest Path Routing Matrix

---

*) see page 11

BRANCH CAPACITY MATRIX

```
              (1)   (2)   (3)   (4)   (5)   (6)   (7)   (8)   (9)  (10)  (11)  (12)  (13)  (14)  (15)
       (1)     0.50000.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
       (2) 50000.    0.50000.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
       (3)     0.50000.    0.    0.50000.    0.    0.50000.    0.    0.    0.    0.    0.    0.50000.
       (4)     0.    0.    0.    0.50000.50000.    0.    0.    0.    0.    0.    0.    0.    0.    0.
       (5)     0.    0.50000.50000.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
 [C] = (6)     0.    0.    0.50000.    0.    0.50000.    0.    0.    0.    0.    0.    0.    0.    0.
       (7)     0.    0.    0.    0.    0.50000.    0.    0.    0.    0.    0.    0.    0.    0.    0.
       (8)     0.    0.50000.    0.    0.    0.    0.    0.50000.50000.    0.    0.    0.    0.    0.
       (9) 0.  0.    0.    0.    0.    0.    0.    0.50000.    0.50000.50000.    0.    0.    0.    0.
      (10)     0.    0.    0.    0.    0.    0.    0.50000.50000.    0.50000.50000.    0.    0.    0.
      (11)     0.    0.    0.    0.    0.    0.    0.    0.50000.50000.    0.50000.50000.    0.    0.
      (12)     0.    0.    0.    0.    0.    0.    0.    0.    0.50000.50000.    0.50000.    0.    0.
      (13)     0.    0.    0.    0.    0.    0.    0.    0.    0.    0.50000.50000.    0.    0.    0.
      (14)     0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.50000.
      (15)     0.    0.50000.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.50000.    0.
```

C(i,j) = Capacity of branch (i,j)

TRAFFIC MATRIX IN BITS/SEC.

$$[T] = \begin{array}{c|ccccccccccccccc}
 & (1) & (2) & (3) & (4) & (5) & (6) & (7) & (8) & (9) & (10) & (11) & (12) & (13) & (14) & (15) \\
\hline
(1) & 0 & 0. & 0. & 2056. & 0. & 1062. & 1713. & 0. & 1485. & 2947. & 1645. & 4363. & 1188. & 902. & 0. \\
(2) & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. \\
(3) & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. \\
(4) & 2056. & 0. & 0. & 0. & 0. & 976. & 1573. & 0. & 1364. & 2706. & 1510. & 4007. & 1091. & 829. & 0. \\
(5) & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. \\
(6) & 1062. & 0. & 0. & 976. & 0. & 0. & 813. & 0. & 705. & 1398. & 780. & 2070. & 564. & 428. & 0. \\
(7) & 1713. & 0. & 0. & 1573. & 0. & 813. & 0. & 0. & 1136. & 2255. & 1259. & 3339. & 909. & 691. & 0. \\
(8) & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. \\
(9) & 1485. & 0. & 0. & 1364. & 0. & 705. & 1136. & 0. & 0. & 1955. & 1091. & 2894. & 788. & 598. & 0. \\
(10) & 2947. & 0. & 0. & 2706. & 0. & 1398. & 2255. & 0. & 1955. & 0. & 2165. & 5743. & 1564. & 1188. & 0. \\
(11) & 1645. & 0. & 0. & 1510. & 0. & 780. & 1259. & 0. & 1091. & 2165. & 0. & 3206. & 873. & 663. & 0. \\
(12) & 4363. & 0. & 0. & 4007. & 0. & 2070. & 3339. & 0. & 2894. & 5743. & 3206. & 0. & 2315. & 1759. & 0. \\
(13) & 1188. & 0. & 0. & 1091. & 0. & 564. & 909. & 0. & 788. & 1564. & 873. & 2315. & 0. & 479. & 0. \\
(14) & 902. & 0. & 0. & 829. & 0. & 428. & 691. & 0. & 598. & 1188. & 663. & 1759. & 479. & 0. & 0. \\
(15) & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0.
\end{array}$$

The entries in this matrix are the amount of traffic in bits per second flowing along the arcs of the network.

MATRIX OF THE AVERAGE # OF MESSAGES/SEC.

$$[\lambda] = \begin{array}{c|ccccccccccccccc}
 & (1) & (2) & (3) & (4) & (5) & (6) & (7) & (8) & (9) & (10) & (11) & (12) & (13) & (14) & (15) \\
(1) & 0. & 27. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. \\
(2) & 27. & 0. & 27. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. \\
(3) & 0. & 27. & 0. & 0. & 49. & 0. & 0. & 64. & 0. & 0. & 0. & 0. & 0. & 0. & 11. \\
(4) & 0. & 0. & 0. & 0. & 49. & 32. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. \\
(5) & 0. & 0. & 49. & 49. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. \\
(6) & 0. & 0. & 0. & 32. & 0. & 0. & 21. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. \\
(7) & 0. & 0. & 0. & 0. & 0. & 21. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. \\
(8) & 0. & 0. & 64. & 0. & 0. & 0. & 0. & 0. & 8. & 56. & 0. & 0. & 0. & 0. & 0. \\
(9) & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 8. & 0. & 3. & 7. & 0. & 0. & 0. & 0. \\
(10) & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 56. & 3. & 0. & 21. & 33. & 0. & 0. & 0. \\
(11) & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 7. & 21. & 0. & 9. & 11. & 0. & 0. \\
(12) & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 33. & 9. & 0. & 3. & 0. & 0. \\
(13) & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 11. & 3. & 0. & 0. & 0. \\
(14) & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 11. \\
(15) & 0. & 0. & 11. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 11. & 0.
\end{array}$$

The values of this matrix represent the average number of messages flowing on branch (i,j). Note that when an entry is zero, the corresponding term in the branch capacity matrix is also zero. i.e. no direct path exists between these two nodes.

NETWORK UTILIZATION MATRIX

$$[\rho] = \begin{array}{cccccccccccccccc}
 & (1) & (2) & (3) & (4) & (5) & (6) & (7) & (8) & (9) & (10) & (11) & (12) & (13) & (14) & (15) \\
(1) & .000 & .217 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 \\
(2) & .217 & .000 & .217 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 \\
(3) & .000 & .217 & .000 & .000 & .398 & .000 & .000 & .518 & .000 & .000 & .000 & .000 & .000 & .000 & .094 \\
(4) & .000 & .000 & .000 & .000 & .398 & .261 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 \\
(5) & .000 & .000 & .398 & .398 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 \\
(6) & .000 & .000 & .000 & .261 & .000 & .000 & .171 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 \\
(7) & .000 & .000 & .000 & .000 & .000 & .171 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 \\
(8) & .000 & .000 & .518 & .000 & .000 & .000 & .000 & .000 & .066 & .452 & .000 & .000 & .000 & .000 & .000 \\
(9) & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .066 & .000 & .024 & .060 & .000 & .000 & .000 & .000 \\
(10) & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .452 & .024 & .000 & .173 & .266 & .000 & .000 & .000 \\
(11) & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .060 & .173 & .000 & .076 & .093 & .000 & .000 \\
(12) & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .266 & .076 & .000 & .029 & .000 & .000 \\
(13) & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .093 & .029 & .000 & .000 & .000 \\
(14) & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .094 \\
(15) & .000 & .000 & .094 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .094 & .000
\end{array}$$

The entry (i,j) is a reflection of the use of that branch. The utilization factor was defined as:

$$\rho(i,j) = \frac{\text{Average number of bits flowing on branch } (i,j)}{\text{Capacity of branch } (i,j) \text{ in bits}}$$

$$\rho(i,j) = \frac{\lambda(i,j)}{\mu'.C(i,j)}$$

An entry $\rho(i,j)$ greater than one implies that the flow exceeded the capacity of the arc. (i,j)

AVERAGE DELAY MATRIX IN SEC/MESSAGE

$$
[A.D] = \begin{array}{cccccccccccccccc}
 & (1) & (2) & (3) & (4) & (5) & (6) & (7) & (8) & (9) & (10) & (11) & (12) & (13) & (14) & (15) \\
(1) & .000 & .017 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 \\
(2) & .017 & .000 & .146 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 \\
(3) & .000 & .146 & .000 & .000 & .149 & .000 & .000 & .152 & .000 & .000 & .000 & .000 & .000 & .000 & .145 \\
(4) & .000 & .000 & .000 & .000 & .019 & .020 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 \\
(5) & .000 & .000 & .149 & .019 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 \\
(6) & .000 & .000 & .000 & .020 & .000 & .000 & .020 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 \\
(7) & .000 & .000 & .000 & .000 & .000 & .020 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 \\
(8) & .000 & .000 & .152 & .000 & .000 & .000 & .000 & .000 & .015 & .021 & .000 & .000 & .000 & .000 & .000 \\
(9) & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .015 & .000 & .015 & .017 & .000 & .000 & .000 & .000 \\
(10) & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .021 & .015 & .000 & .018 & .020 & .000 & .000 & .000 \\
(11) & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .017 & .018 & .000 & .015 & .017 & .000 & .000 \\
(12) & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .020 & .015 & .000 & .016 & .000 & . \\
(13) & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .017 & .016 & .000 & .000 & .000 \\
(14) & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .015 \\
(15) & .000 & .000 & .145 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .015 & .000
\end{array}
$$

The entries of this matrix represent the average delay encountered by a message flowing on branch (i,j).

Total Average Delay = .2444 sec/mess.

SHORTEST PATH ROUTING MATRIX

$$[R] = \begin{array}{c|ccccccccccccccc}
 & (1) & (2) & (3) & (4) & (5) & (6) & (7) & (8) & (9) & (10) & (11) & (12) & (13) & (14) & (15) \\
\hline
(1) & 1 & 2 & 2 & 5 & 3 & 5 & 6 & 3 & 8 & 8 & 10 & 10 & 11 & 15 & 3 \\
(2) & 1 & 2 & 3 & 5 & 3 & 5 & 6 & 3 & 8 & 8 & 10 & 10 & 11 & 15 & 3 \\
(3) & 2 & 2 & 3 & 5 & 5 & 5 & 6 & 8 & 8 & 8 & 10 & 10 & 11 & 15 & 15 \\
(4) & 5 & 5 & 5 & 4 & 5 & 6 & 6 & 5 & 8 & 8 & 10 & 10 & 11 & 15 & 5 \\
(5) & 3 & 3 & 3 & 4 & 5 & 4 & 6 & 3 & 8 & 8 & 10 & 10 & 11 & 15 & 3 \\
(6) & 5 & 5 & 5 & 4 & 4 & 6 & 7 & 5 & 8 & 8 & 10 & 10 & 11 & 15 & 5 \\
(7) & 6 & 6 & 6 & 6 & 6 & 6 & 7 & 6 & 8 & 8 & 10 & 10 & 11 & 15 & 6 \\
(8) & 3 & 3 & 3 & 5 & 3 & 5 & 6 & 8 & 9 & 10 & 10 & 10 & 11 & 15 & 3 \\
(9) & 8 & 8 & 8 & 8 & 8 & 8 & 8 & 8 & 9 & 10 & 11 & 11 & 11 & 15 & 8 \\
(10) & 8 & 8 & 8 & 8 & 8 & 8 & 8 & 8 & 9 & 10 & 11 & 12 & 11 & 15 & 8 \\
(11) & 10 & 10 & 10 & 10 & 10 & 10 & 10 & 10 & 9 & 10 & 11 & 12 & 13 & 15 & 10 \\
(12) & 10 & 10 & 10 & 10 & 10 & 10 & 10 & 10 & 11 & 10 & 11 & 12 & 13 & 15 & 10 \\
(13) & 11 & 11 & 11 & 11 & 11 & 11 & 11 & 11 & 11 & 11 & 11 & 12 & 13 & 15 & 11 \\
(14) & 15 & 15 & 15 & 15 & 15 & 15 & 15 & 15 & 15 & 15 & 15 & 15 & 15 & 14 & 15 \\
(15) & 3 & 3 & 3 & 5 & 3 & 5 & 6 & 3 & 8 & 8 & 10 & 10 & 11 & 14 & 15
\end{array}$$

This matrix should be read in the following way:

$r(i,j) = j \Longrightarrow$ The path connecting node i and j does not contain any intermediate nodes.

$r(i,j) = k \neq j \Longrightarrow$ node k is an intermediate node on the path between nodes i and j.

CHAPTER III

TeleSat

Telesat Canada
333 River Road
Ottawa, Ontario
Postal code K1L 8B9

(613) 746-5920

File No. 24-2-1-1
February 23, 1972

Dr. J. deMercado,
Director,
Terrestrial Systems Planning,
Department of Communications,
Berger Building,
100 Metcalfe Street,
Ottawa, Ontario
K1A 0C8

Dear Dr. deMercado:

As a result of discussions with members of your staff, we are pleased to submit for your information, preliminary engineering cost estimates and technical information for providing data transmission services for the proposed "Canadian University Computer Network".

It should be emphasized that this information is very preliminary in nature and is intended only for the use by CANUNET participants to establish whether or not further detailed study would be of value. As such, the cost information could change when detailed system requirements are defined and commercial arrangements are known.

You will note that Telesat Canada has provided information in the Attachment on utilization of a whole R.F. channel by a number of networks, one of which could conceivably be CANUNET. The minimum cost per network is achieved when the satellite R.F. channel is fully utilized. The practicability of achieving the per network minimum cost depends on the number of networks that may be established and the consequent extent of the R.F. channel cost sharing that can be achieved.

. . .

With regard to R.F. channel cost sharing, it is possible that another network similar to CANUNET could be implemented to serve Federal Government integrated data transmission requirements more economically. In addition, other networks for use by various professional communities such as law, medicine, etc., could probably be developed to exploit the most cost effective configuration.

The estimated charges are based on service at the earth stations outlined; we understand backhaul interconnection costs to the various universities from our earth stations will be developed within your Department.

Telesat Canada is prepared to undertake a more detailed engineering analysis in support of CANUNET and Federal Government data transmission requirements in order to arrive at the most effective overall system configuration.

Mr. P.M. Norman will be pleased to continue liaison with your staff on technical matters and Mr. B.F. Murphy of our Planning and Marketing group will be contacting you as well to discuss any further information you require in connection with the estimated annual charges for the various network configurations.

Yours sincerely,

RMLester

R.M. Lester,
Director,
Communication Systems.

Attach.

ATTACHMENT TO LETTER TO

Dr. J. de Mercado

SATELLITE COMMUNICATIONS SYSTEM FOR DATA TRANSMISSION (CANUNET)

Telesat Canada
Ottawa
February 23, 1972

TABLE OF CONTENTS

I INTRODUCTION

This study illustrates the application of the Telesat satellite telecommunication system for use in the provision of communication services to CANUNET. Particular emphasis is placed on those features which offer unique capabilities in the provision of the service. Several possible network configurations have been examined and are illustrated. With the budgetary costs and system concept provided, it is possible for other networks to be assembled to enable the designers of CANUNET to select the most appropriate system.

The information provided here is preliminary in nature and is intended to form a basis for further discussion. The system design concepts and estimated facility annual charges can only be firm after further studies with CANUNET personnel to better relate the satellite system design to the network needs. Furthermore, commercial rates may introduce other factors not taken into account in an engineering study.

II INITIAL TELESAT SATELLITE SYSTEM

The initial satellite system is planned for commercial operation by Telesat in January 1973. At that time, some 36 earth stations will be in operation providing high quality voice, data, facsimile and television transmission across Canada. Figure 1 shows the initial locations of these earth stations. Of primary interest to CANUNET will be those earth stations located in Southern Canada.

The space segment will normally consist of two in-orbit satellites. One satellite will be in operation while the second will provide back-up protection in case of failure of the first. Each satellite has 12 RF channels, 10 of which are available for full time commercial operation and 2 for standby operation. The use of two satellites in orbit and RF channel protection within each satellite provides the high degree of system reliability which is necessary for the proper operation of important communications services.

The RF channels each have the capability for carrying up to 60 Mb/s or 960 one-way voice channels depending on the modulation scheme and type of earth station used. The capability of the system for voice and television applications as well as a more detailed system description is contained in the attached paper "Communications Capability of the Canadian Domestic Satellite System".*

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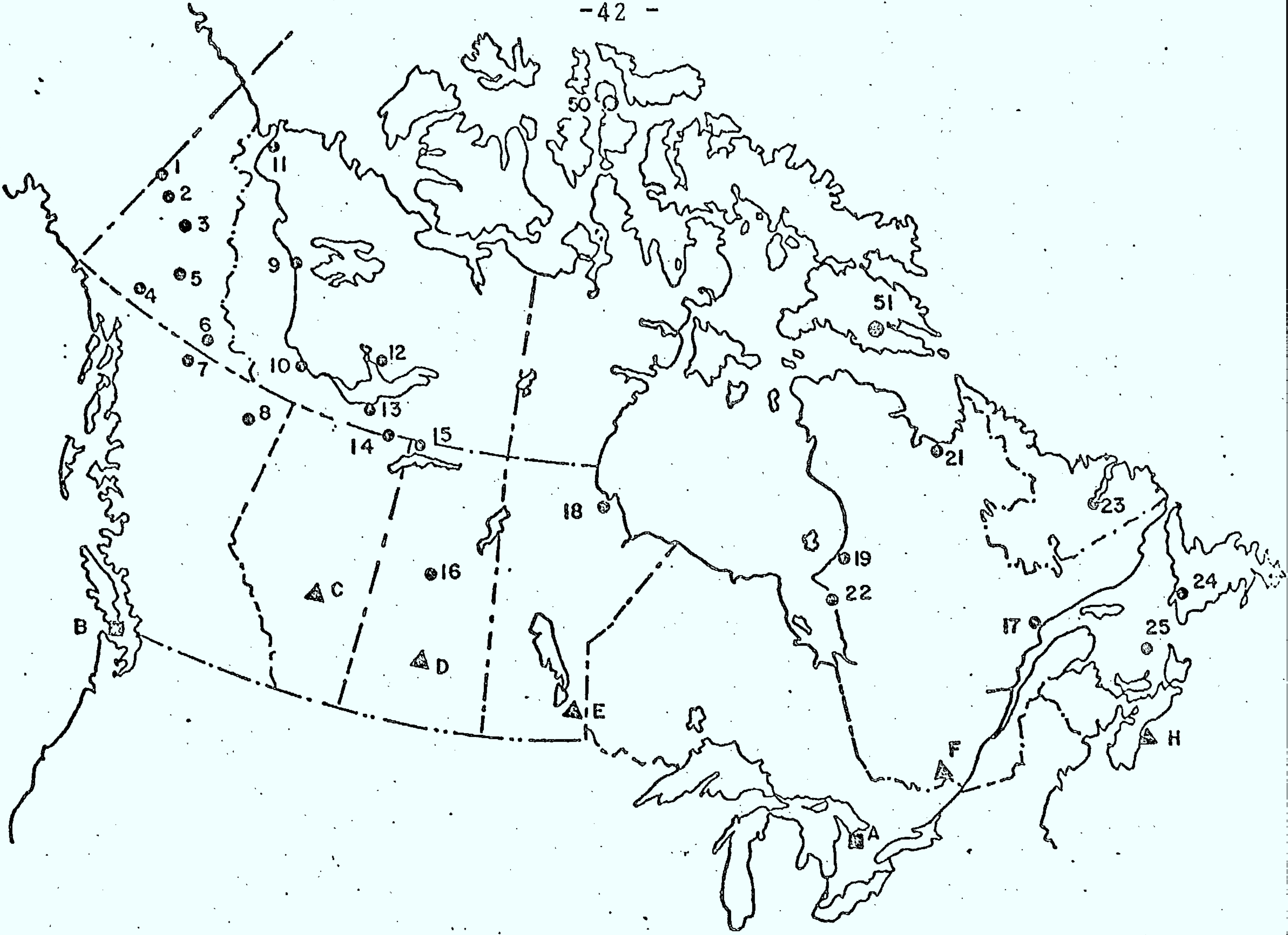
*J. Almond and R.M. Lester: "Communications Capability of the Canadian Domestic Satellite System." ICC Conference Paper, June 1971.



HEAVY ROUTE ▣

A. Allan Park
B. Lake Cowichan

NETWORK TELEVISION ▲

C. Huggett
D. Qu'Appelle
E. Grand Beach
F. Riviere Rouge
G. Bay Bulls
H. Harrietsfield

NORTHERN TELECOMMUNICATIONS ⊛

50. Resolute
51. Frobisher Bay

REMOTE TELEVISION ⊛

1. Clinton Creek
2. Dawson
3. Elsa
4. Whitehorse
5. Faro
6. Watson Lake
7. Cassiar
8. Fort Nelson
9. Norman Wells
10. Fort Simpson
11. Inuvik
12. Yellowknife
13. Pine Point
14. Fort Smith
15. Uranium City
16. La Ronge
17. Sept Iles
18. Churchill
19. Great Whale
21. Fort Chimo
22. Fort George
23. Goose Bay
24. Port-au-Port
25. Magdalen Islands

Figure 1 INITIAL TELESAT EARTH STATION LOCATIONS

III PROPOSED SYSTEM FOR CANUNET

SYSTEM CONFIGURATION

Suitable communication system designs have been examined to provide bit rates of 9.6 and 50 kb/s interconnecting the Nodes shown in some of the Networks that have been proposed for CANUNET*. These Nodes are given in Table I. All schemes would require a combination of terrestrial and satellite facilities in order to provide the overall service. The characteristics of the proposed system to provide the satellite facilities are described in the ensuing paragraphs.

The system concept planned by Telesat would use a separate radio frequency carrier for each data stream transmitted through the satellite RF channel. This is the scheme illustrated in Figure 2. Each satellite RF channel can accommodate up to 70 carriers, each carrying data at up to 50 kb/s or approximately double the number of carriers at 9.6 kb/s. At a 50 kb/s bit rate the PSK modulator would operate at a nominal 64 kb/s and through the use of forward acting error correcting coders could provide a typical error rate of 1 in 10^7 for 99.9% of the time or better. Other trade-offs in bit rate, error rate and satellite utilization are possible. If desired, it would also be possible to combine bit streams at 9.6 kb/s or lower rates into single streams transmitted over the satellite at higher rates. Thus, any data rate could be selected by CANUNET to be compatible with that carried on the terrestrial network between the earth stations and Nodes so that no buffering would be required.

In the specific configuration that is proposed for CANUNET each earth station would be assigned one channel having a bit rate of 9.6 or 50 kb/s and having a unique transmit frequency. Furthermore, each earth station would be equipped with receivers tuned to the transmit frequencies of all the other

---

*J. de Mercado, R. Guindon, J. Da Silva, M. Kadoch: Topological Analysis and Design of CANUNET. January 1972.

TABLE I

CANUNET NODES

10 Node Network	14 Node Network		18 Node Network	
Vancouver	Vancouver	Montreal	Vancouver	Hamilton
Calgary	Calgary	Quebec	Calgary	Windsor
Saskatoon	Edmonton	Fredericton	Edmonton	Montreal
Winnipeg	Regina	Halifax	Regina	Quebec
Ottawa	Saskatoon		Saskatoon	Fredericton
Toronto	Winnipeg		Winnipeg	Moncton
Waterloo	Ottawa		Ottawa	Charlottetown
Montreal	Toronto		Toronto	Halifax
Quebec	Waterloo		Waterloo	
Halifax	Kingston		Kingston	

Figure 2

SATELLITE UTILIZATION SCHEME FOR CANUNET

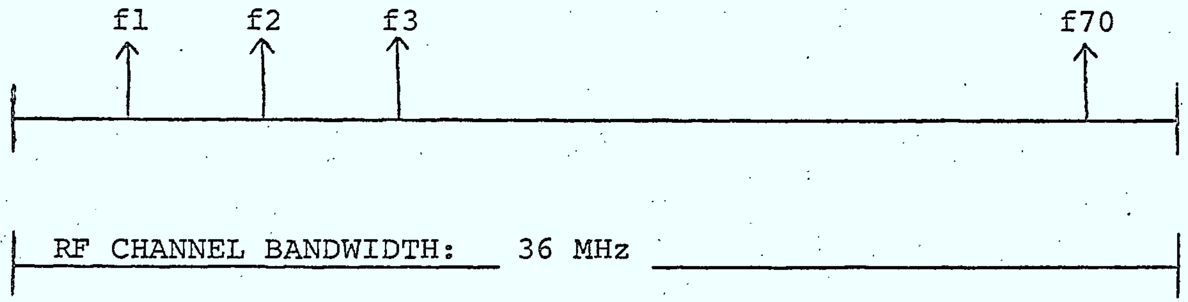
PSK - FDMA MODULATION

EXAMPLE

NETWORK OF 2 TO 8 EARTH STATIONS

EARTH STATION G/T = 28 dB

APPROX. 70 CHANNELS AT 50 kb/s EACH THROUGH 1 RF CHANNEL (OR 140 AT 9.6 kb/s)



FEATURES

- 70 FREQUENCIES (i.e. CHANNELS) AVAILABLE TO EACH STATION (OR 140 AT 9.6 kb/s)
- EACH STATION CAN TRANSMIT ANY NUMBER OF CHANNELS
- A FREQUENCY TRANSMITTED BY ONE STATION CAN BE RECEIVED BY ONE OR ANY NUMBER OF OTHER STATIONS SIMULTANEOUSLY AS REQUIRED. THIS PROVIDES A FLEXIBLE ADAPTIVE ROUTING CAPABILITY.
- THIS SCHEME CAN BE ADAPTED TO PROVIDE FOR THE ASSIGNMENT OF CHANNELS BETWEEN DIFFERENT LOCATIONS ON DEMAND; i.e. DEMAND ASSIGNMENT BY COMPUTER CONTROL.
- ERROR RATE 1 in 10^7 FOR 99.9% OF THE TIME OR BETTER.

earth stations in the network. Transmissions from any earth station will thus be received by all other earth stations in the network but will only be accepted for onward transmission upon recognition of an address appropriate to its destination. The addresses are assumed to be inserted at the originating universities and assembled into the data streams for transmission over the satellite system. This would result in an adaptive route selection capability since a message transmitted by any one earth station can be received by any number of earth stations simultaneously. Thus, individual direct links between any earth stations in Canada so equipped can be established on demand using the same specific channel in the satellite without passage through intervening Nodes. It is understood that such an arrangement with one channel transmitted per station would quite adequately meet CANUNET requirements.

The network configuration that has been described with earth stations equipped to receive data from more than one location could result in several bit streams being received simultaneously. It is assumed that CANUNET would arrange for the necessary recognition of addresses and any funnelling of data for transmission on the terrestrial network to the nearest Node.

Other arrangements than that described would, of course, be possible. For example, earth stations could transmit more than one radio frequency carrier at 9.6, 50 kb/s, or other bit rates. Furthermore, certain high usage links between Nodes could have dedicated, pre-assigned lines which would not be received by other stations. These features, to provide for growth after the initial system is in service, may easily be added on an incremental basis.

EARTH STATION LOCATIONS

The total cost of the communication system to provide service to CANUNET will be a combination of both the cost of satellite and terrestrial facilities. Telesat has attempted to select earth station locations which would provide the most cost effective solution to CANUNET. However, the total cost is a complex function of the overall network configuration and it is expected that the specific number of earth station accesses to the satellite will need to be considered carefully by the designers of CANUNET.

CANUNET is considering the interconnection of universities homing on either ten, fourteen or eighteen Nodes as illustrated in Table I.

Consideration of these requirements in relation to the presently planned Telesat earth stations listed in Table II reveals that about 50% of the locations are less than 100 miles from a Telesat earth station, 70% less than 150 miles and that 100% are within approximately 220 miles. These distances are based on the most probable routing of the terrestrial facilities required to link the city to the Telesat earth station and could be somewhat less if more direct links are available. However, they do not include route mileage required to link the individual universities to their respective Node Control Units.

The location of the presently planned earth stations in relation to the Nodes suggests that these stations could effectively be used to provide the long distance communication facilities for CANUNET. A preliminary examination of sites for new earth stations indicates that it would be more economic to use the existing ones. However, Telesat would be pleased to assist in considering such new earth stations should it become desirable.

Using the existing earth stations in Southern Canada which are shown in Table II, seven regional CANUNET networks could be established and interconnected via satellite as shown in Figure 3. The inclusion of St. John's, Nfld., although not shown as a Node could also easily be accomplished using the existing Bay Bulls station. Figure 4 illustrates other possible regional networks using different numbers of earth stations. These are based on minimizing the terrestrial mileage in each case.

TABLE II

Location of Earth Stations in Southern Canada

Name	Closest Major Centres of Population	Approximate Distance
Bay Bulls	St. John's, Nfld.	17 miles
Harrietsfield	Halifax, Nfld.	10
Riviere Rouge	Montreal, P.Q.	55
Allan Park	Toronto, Ont.	80
	Waterloo, Ont.	60
Grand Beach	Winnipeg, Man.	55
Qu'Appelle	Regina, Sask.	27
	Saskatoon, Sask.	140
Huggett	Edmonton, Alta.	26
	Calgary, Alta.	150
Lake Cowichan	Victoria, B.C.	40
	Vancouver, B.C.	55

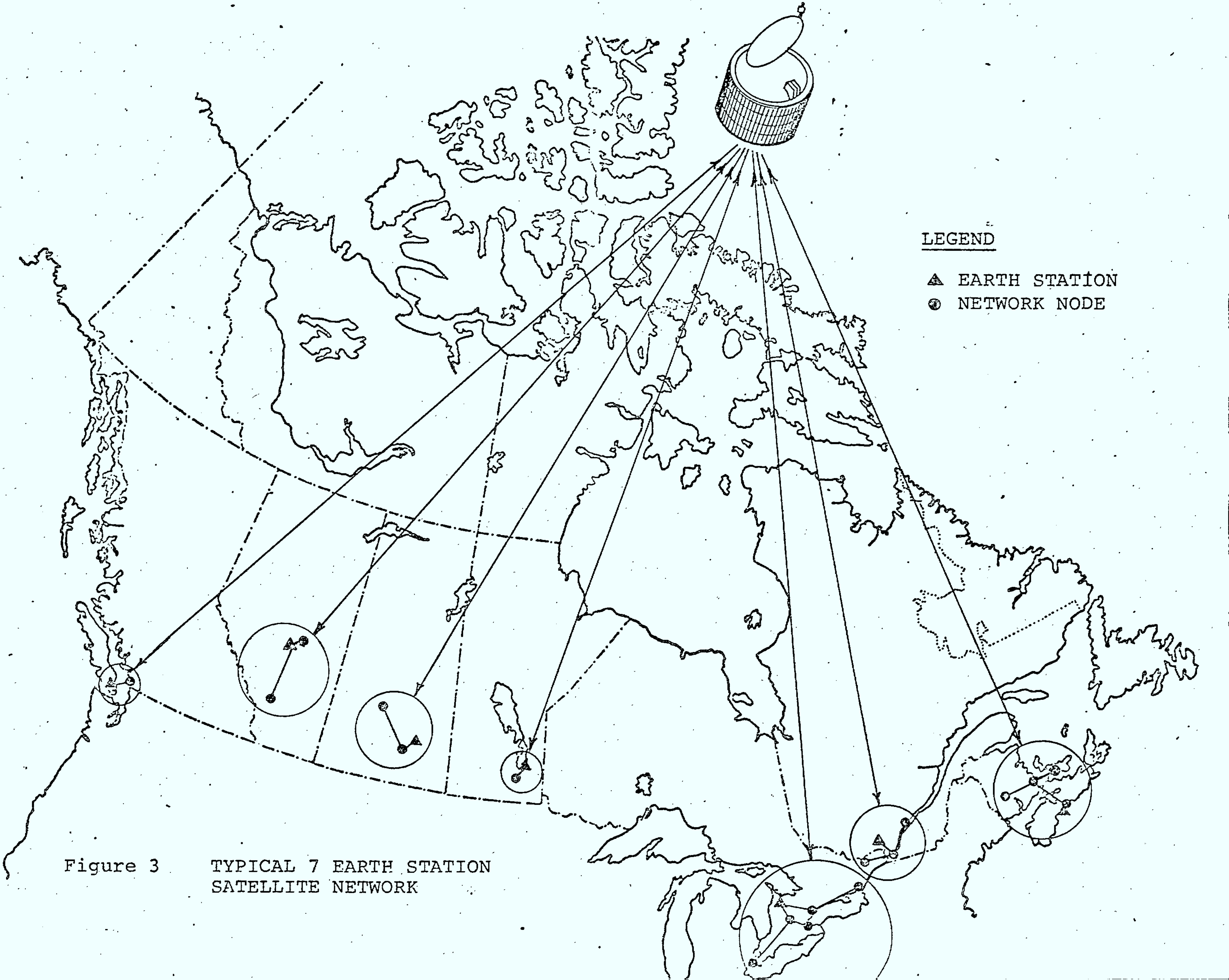


Figure 3 TYPICAL 7 EARTH STATION SATELLITE NETWORK

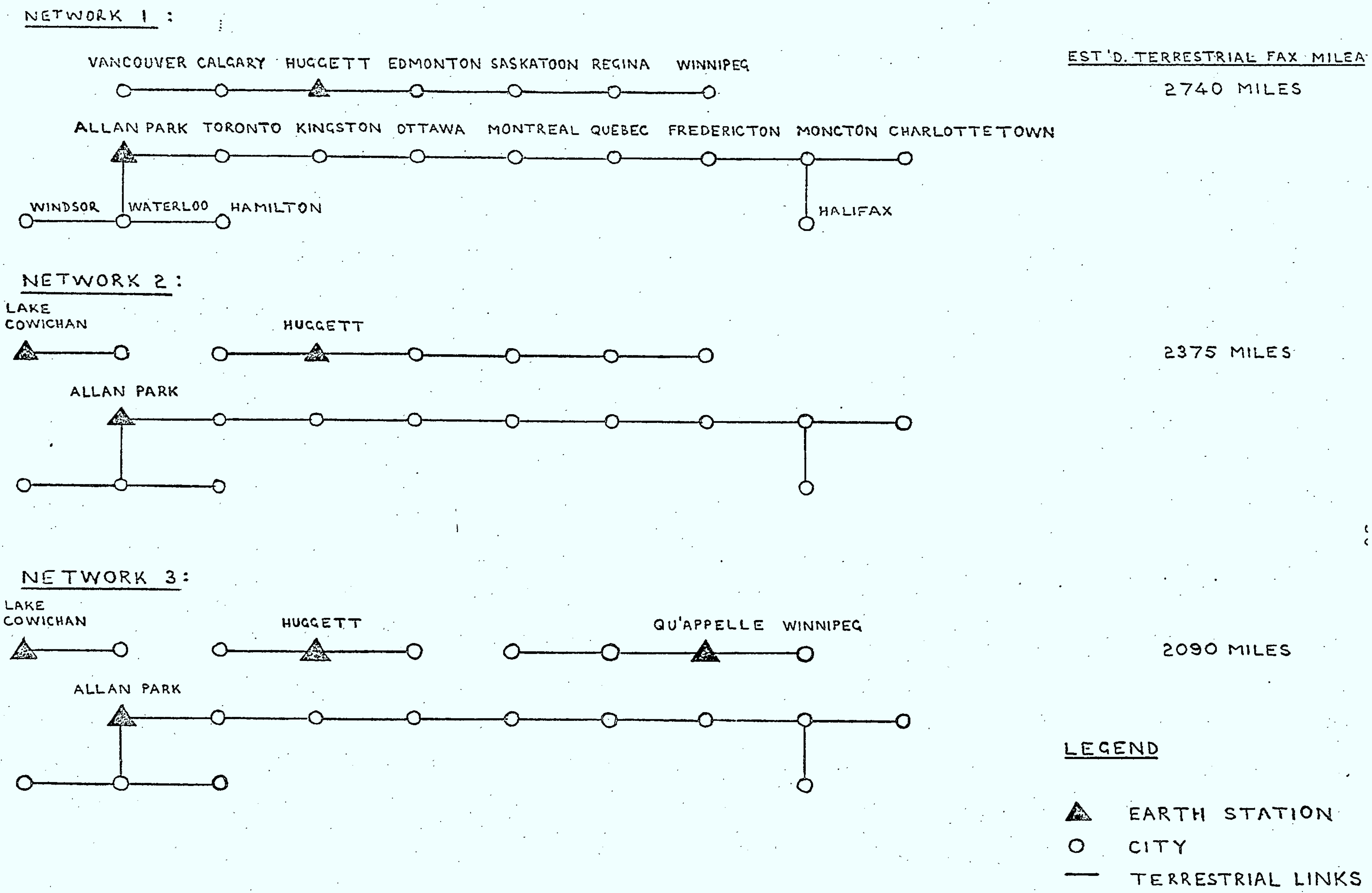


FIGURE 4 TYPICAL NETWORK CONFIGURATIONS

SH.1. CONTINUED ON SH. 2

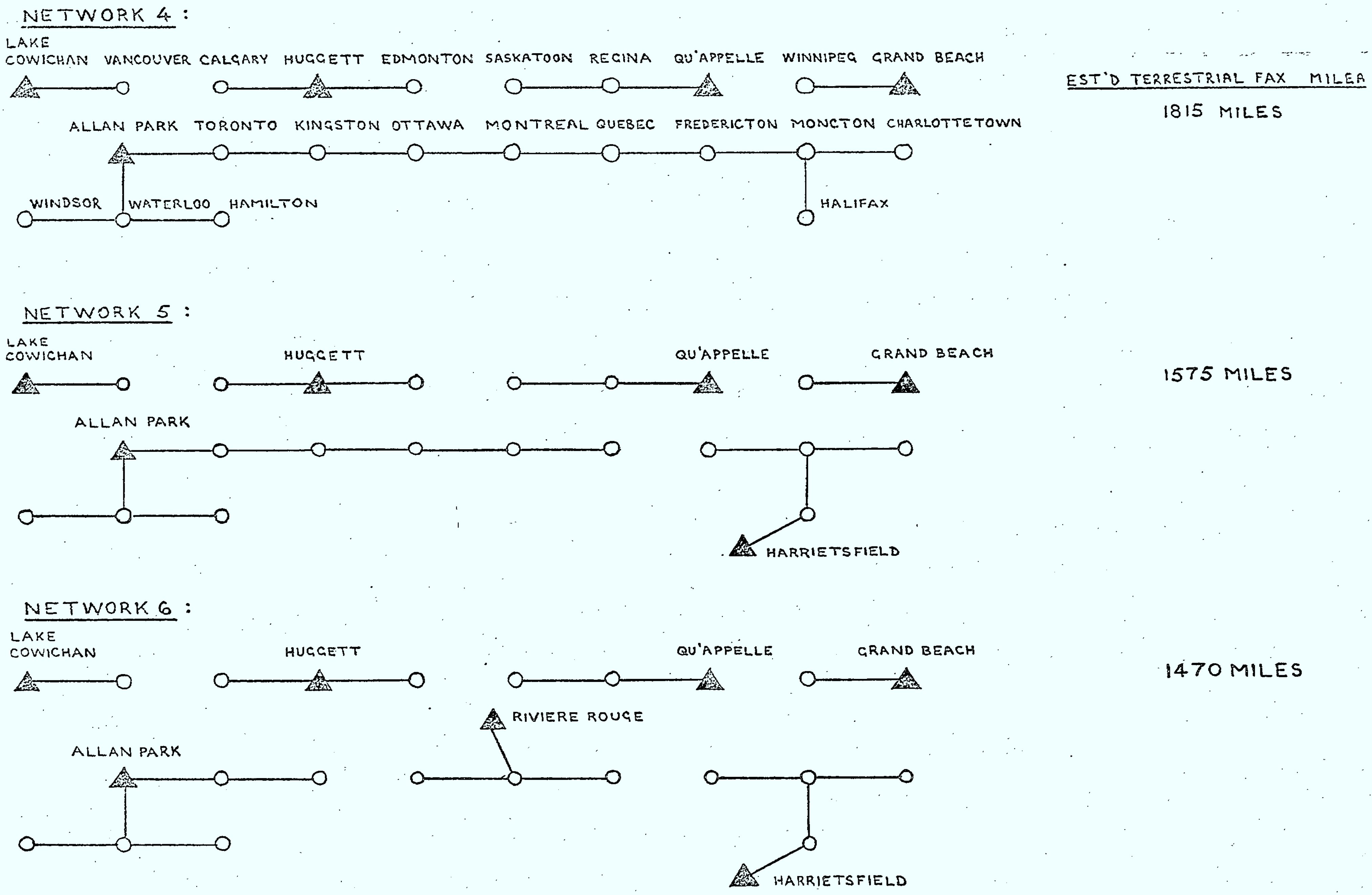


FIGURE 4 TYPICAL NETWORK CONFIGURATIONS

SH. 2 . FINAL

NETWORK FLEXIBILITY

The system outlined possesses considerable flexibility and operational advantages especially in configurations involving more than 2 (two) earth stations. In the first place the system possesses a multi-point interconnection capability and any regional network is directly connected via a single satellite link to any other regional network. This is illustrated for a simple 3 earth station network in figure 5. The channel reliability and/or quality is thus independent of the distance between the interconnected networks in contrast to the situation using terrestrial facilities where the possibility of impairment or failure is proportional to the length of the channel involved.

Secondly, the grouping of Nodes into regional networks possessing a community of interest would tend to reduce the load on the long distance satellite links thus reducing queuing problems which might arise on a single trunk terrestrial scheme.

Thirdly, the network can be set up with only the interconnection capability initially required. Additional interconnection capability is very easily added by the provision of the necessary transmitters or receivers at the stations concerned.

SYSTEM RELIABILITY AND SERVICE AVAILABILITY

The reliability of the system for data traffic may be measured in terms of the error rate. A typical error rate of 1 in 10^7 for 99.9% of the time has been assumed. Other trade-offs in error rate, bit rates and satellite RF channel utilization are possible.

The service availability objective would be to provide a two-way continuity of service of 99.98% of the time or better.

TIME DELAY

A significant design criteria in the CANUNET network is the time delay for a message to reach its destination. For a network using satellite facilities it is expected that the

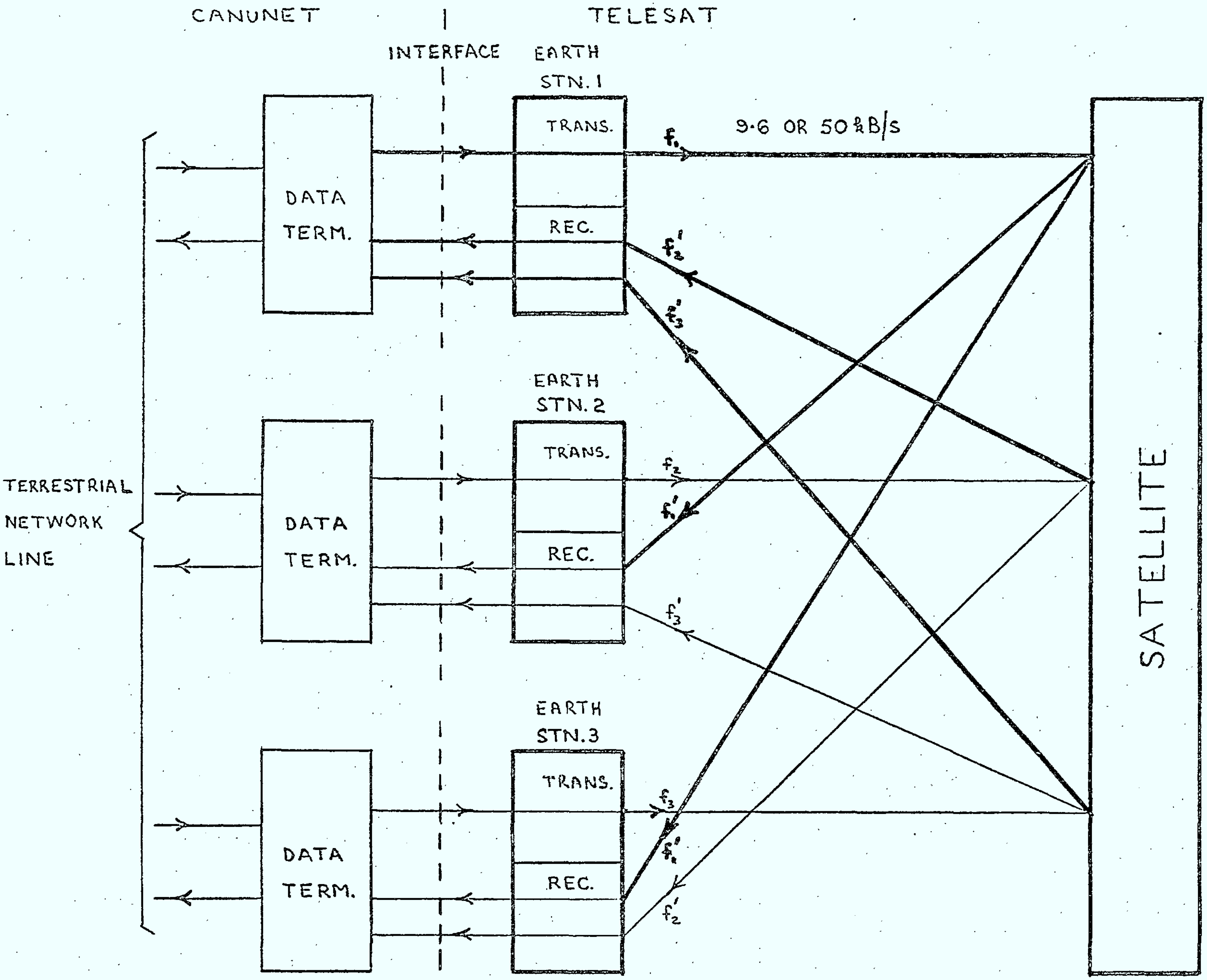


FIGURE 5 TYPICAL SYSTEM LAYOUT - 3 STATION CONFIGURATION

significant contributor to this will be propagation delay. However, delay which results from queuing at Nodes is not expected to be as significant as on the terrestrial network since an earth station transmitting to another can effectively leap frog the intervening Nodes.

The actual propagation delay via satellite will vary somewhat with the position of the satellite and the location of the earth stations. For design purposes it is suggested that a propagation delay of between 250 and 270 milliseconds be used for a one way link from a transmitting to receiving earth station. More precise values could be provided if desired.

COSTS

The costs associated with the rental of satellite facilities are discussed in the letter of transmittal with this Attachment. To further assist CANUNET in the planning of their network, separate estimates of annual charges have been made for a satellite system using from 2 - 8 earth stations. These are budgetary estimates only and would have to be refined to reflect further discussion concerning the system configuration. These estimates may be used for example, to assist in decisions on the economics of adding or removing earth stations, since the overall system cost to CANUNET would involve a combination of the terrestrial and satellite facility costs.

TABLE III

50 or 9.6 kb/s

TOTAL ANNUAL CHARGE $ MILLION
ANNUAL CHARGE PER NETWORK $ MILLION

	NUMBER OF NETWORKS													
NO. OF STATIONS PER NETWORK	1	2	3	4	5	6	8	10	15	20	25	30	35	70
2	3 3	3 1.5	3 1.0	3 0.75	3 0.6	3 0.5	3 0.38	3.08 0.31	3.55 0.24	4.03 0.20	4.50 0.18	4.98 0.17	5.45 0.16	8.78 0.13
3	3 3	3 1.5	3 1.0	3 0.75	3 0.6	3.10 0.52	3.41 0.43	3.73 0.37	4.52 0.30	5.31 0.27	6.10 0.27	6.89 0.23	7.68 0.22	
4	3 3	3 1.5	3 1.0	3.09 0.77	3.32 0.66	3.56 0.59	4.02 0.50	4.48 0.45	5.64 0.38	6.79 0.34	7.95 0.35	9.10 0.30	10.26 0.29	
5	3 3	3 1.5	3.14 1.05	3.45 0.86	3.77 0.75	4.08 0.68	4.71 0.59	5.34 0.53	6.92 0.46	8.49 0.43	10.01 0.40			
6	3 3	3.03 1.5	3.44 1.15	3.85 0.96	4.27 0.85	4.68 0.78	5.50 0.69	6.32 0.63	8.38 0.56	10.43 0.52				
7	3 3	3.26 1.63	3.78 1.29	4.29 1.07	4.81 0.96	5.32 0.89	6.35 0.79	7.38 0.74	9.96 0.66	12.53 0.63				
8	3 3	3.52 1.76	4.15 1.38	4.78 1.20	5.41 1.08	6.04 1.01	7.30 0.91	8.56 0.86	11.71 0.78	14.86 0.74				

50 and 9.6 kb/s ← → 9.6 kb/s

NOTES:

1. Assumes the use of existing Telesat earth stations. Costs for the addition of new earth stations could be provided if required.

2. Each earth station in a network is equipped to transmit one channel at the data rate specified

3. Each earth station in a network is equipped to receive the channels from all other earth stations in the same network simultaneously.

4. $3 M per year has been established as the minimum rental for an RF channel and a complement of earth station equipment.

PART II

TERRESTRIAL NETWORKS FOR CANUNET

Introduction

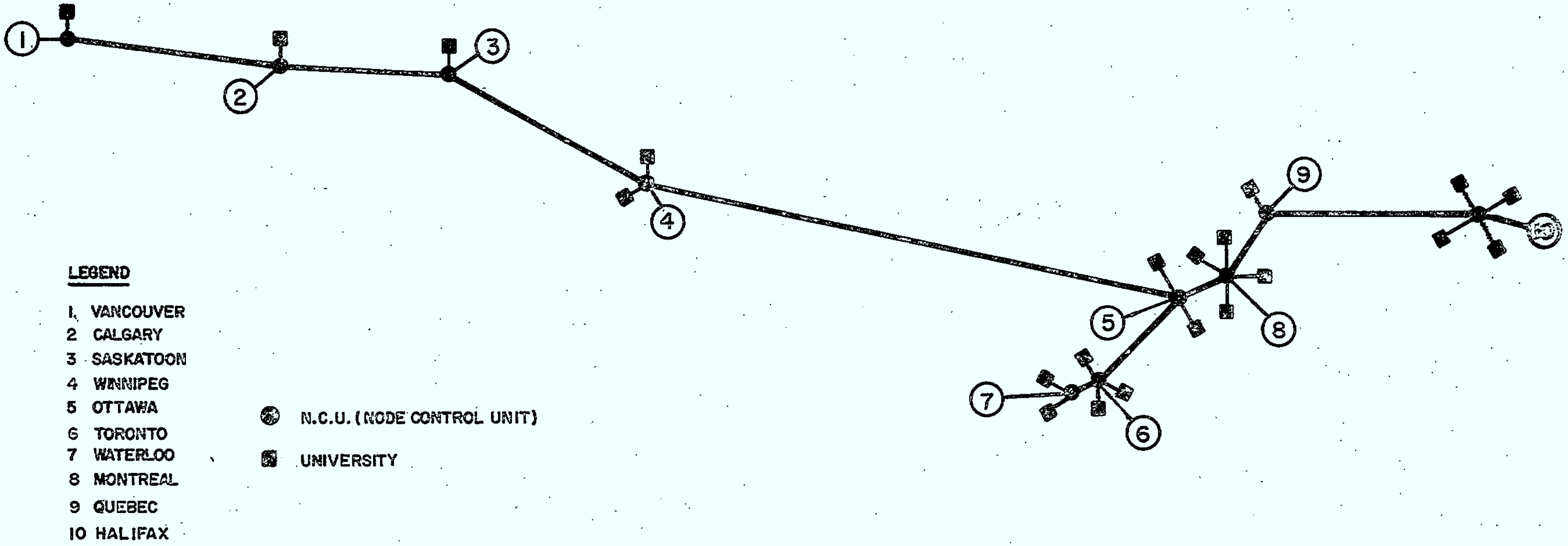
This part contains revised performance graphs of the networks analyzed in the first preliminary report "Topological Analysis and Design of CANUNET" - January 1972.

Due to refinements to the model used to simulate CANUNET, this section was added so that proper comparison could be made with the results of the hybrid simulation which were obtained using this refined version.

In Chapter IV network topologies and performance graphs are given and in Chapter V a detailed simulation of a 10 node terrestrial network is presented. In fact, detailed simulations were carried out for all the networks and,for the sake of brevity these have not been reproduced here but are summarized by the performance graphs.

CHAPTER IV

NETWORK I



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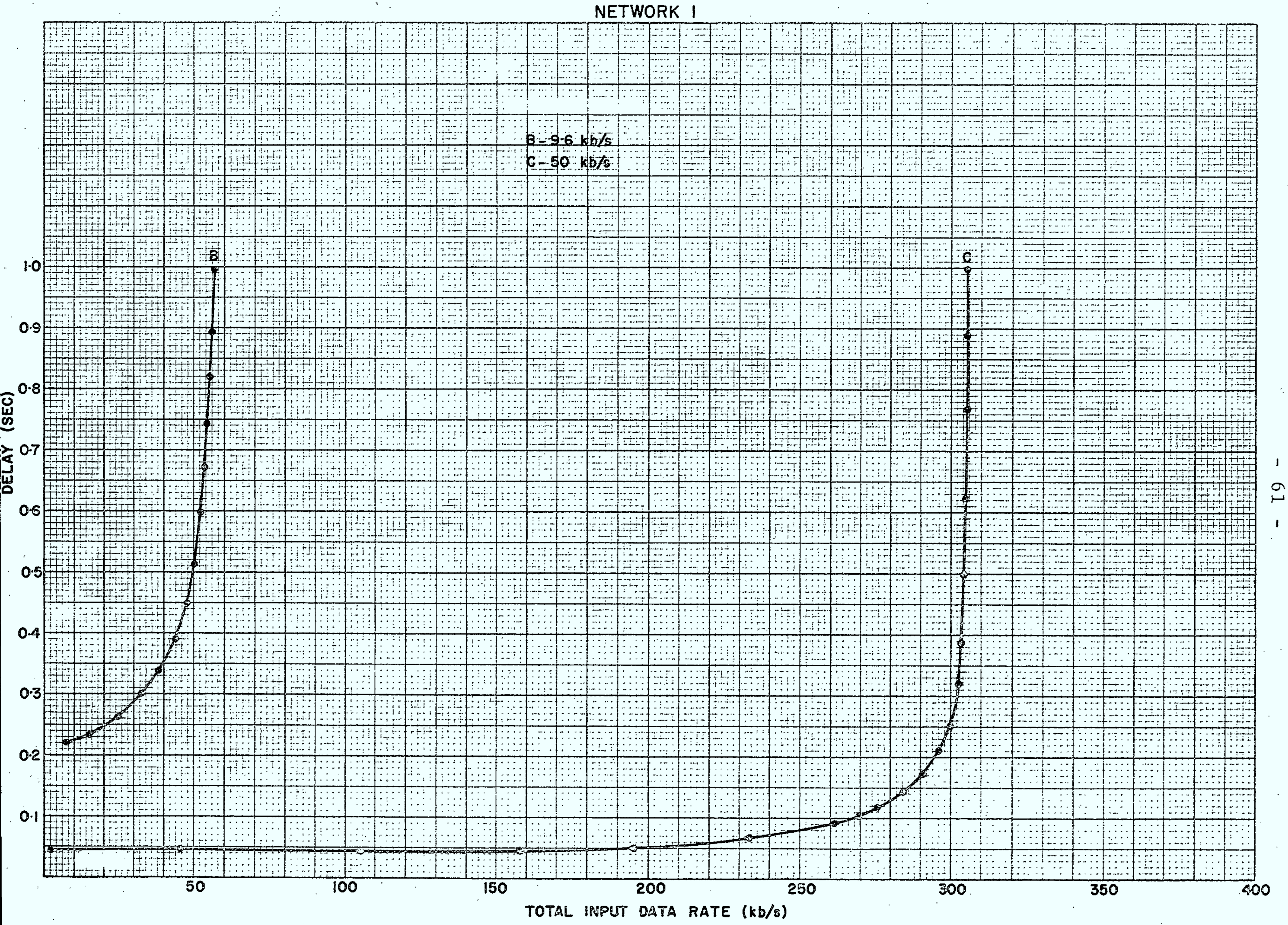
LEGEND
1 VANCOUVER
2 CALGARY
3 SASKATOON
4 WINNIPEG
5 OTTAWA
6 TORONTO
7 WATERLOO
8 MONTREAL
9 QUEBEC
10 HALIFAX
N.C.U. (NODE CONTROL UNIT)
UNIVERSITY


NETWORK I
B - 9·6 kb/s
C - 50 kb/s
B
C
DELAY (SEC)
1·0
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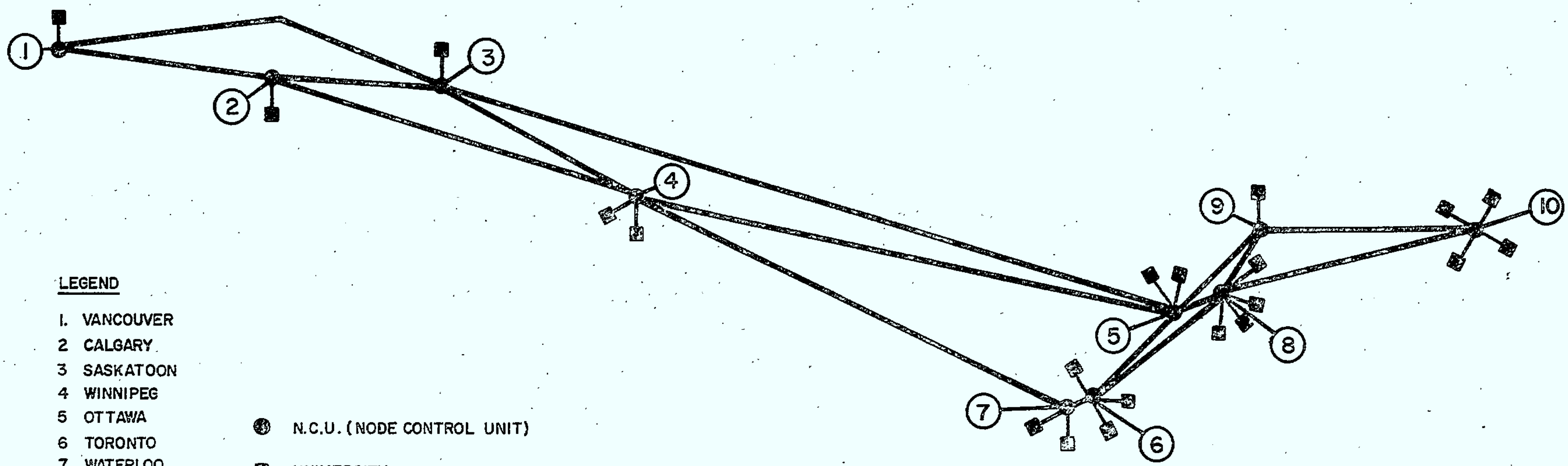
TOTAL INPUT DATA RATE (kb/s)

NETWORK 2

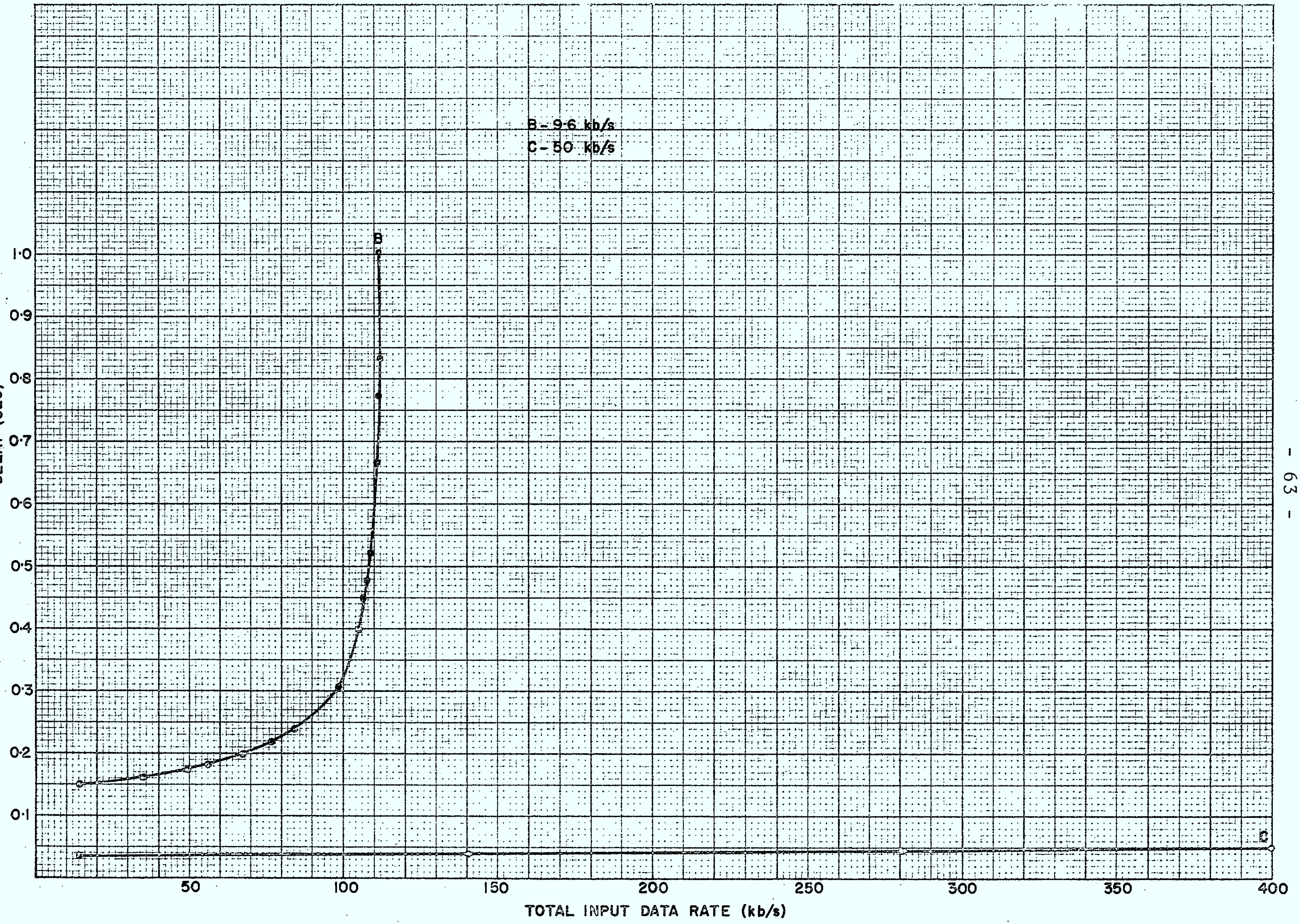


LEGEND

1. VANCOUVER
2. CALGARY
3. SASKATOON
4. WINNIPEG
5. OTTAWA
6. TORONTO
7. WATERLOO
8. MONTREAL
9. QUEBEC
10. HALIFAX

● N.C.U. (NODE CONTROL UNIT)

▨ UNIVERSITY



NETWORK 2

B - 9·6 kb/s
C - 50 kb/s
B
C
DELAY (SEC)
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
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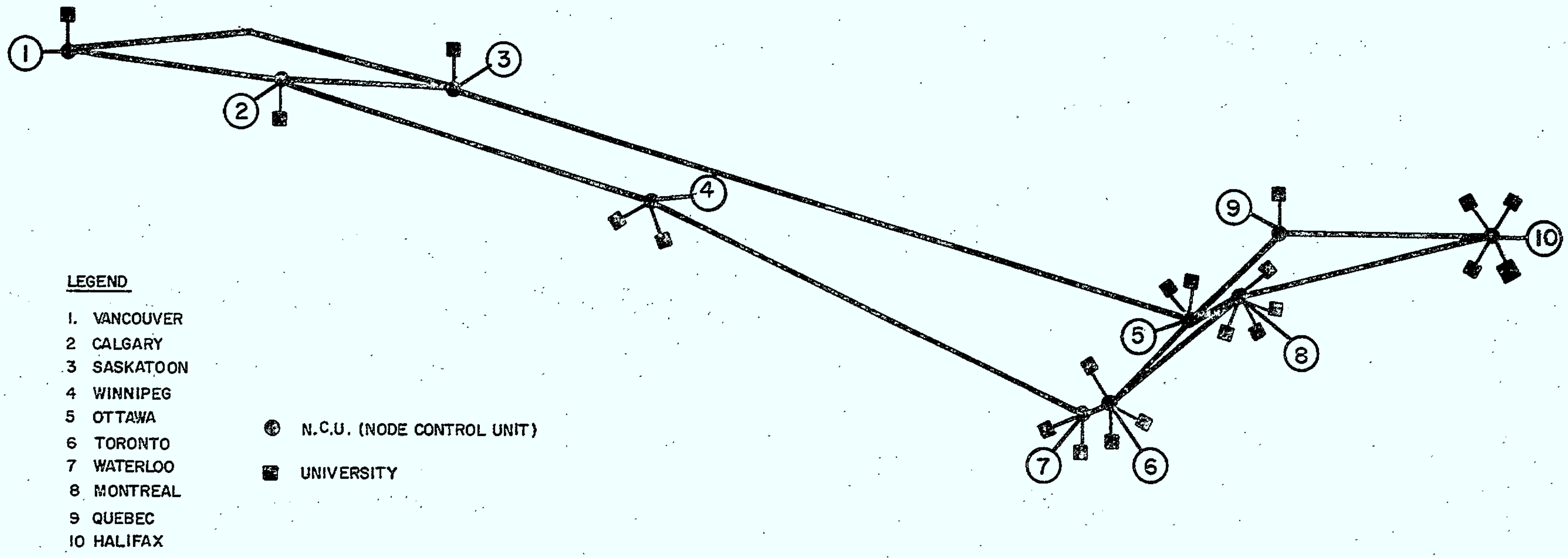
100
150
200
250
300
350
400
TOTAL INPUT DATA RATE (kb/s)

NETWORK 3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LEGEND
1. VANCOUVER
2 CALGARY
3 SASKATOON
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5 OTTAWA
6 TORONTO
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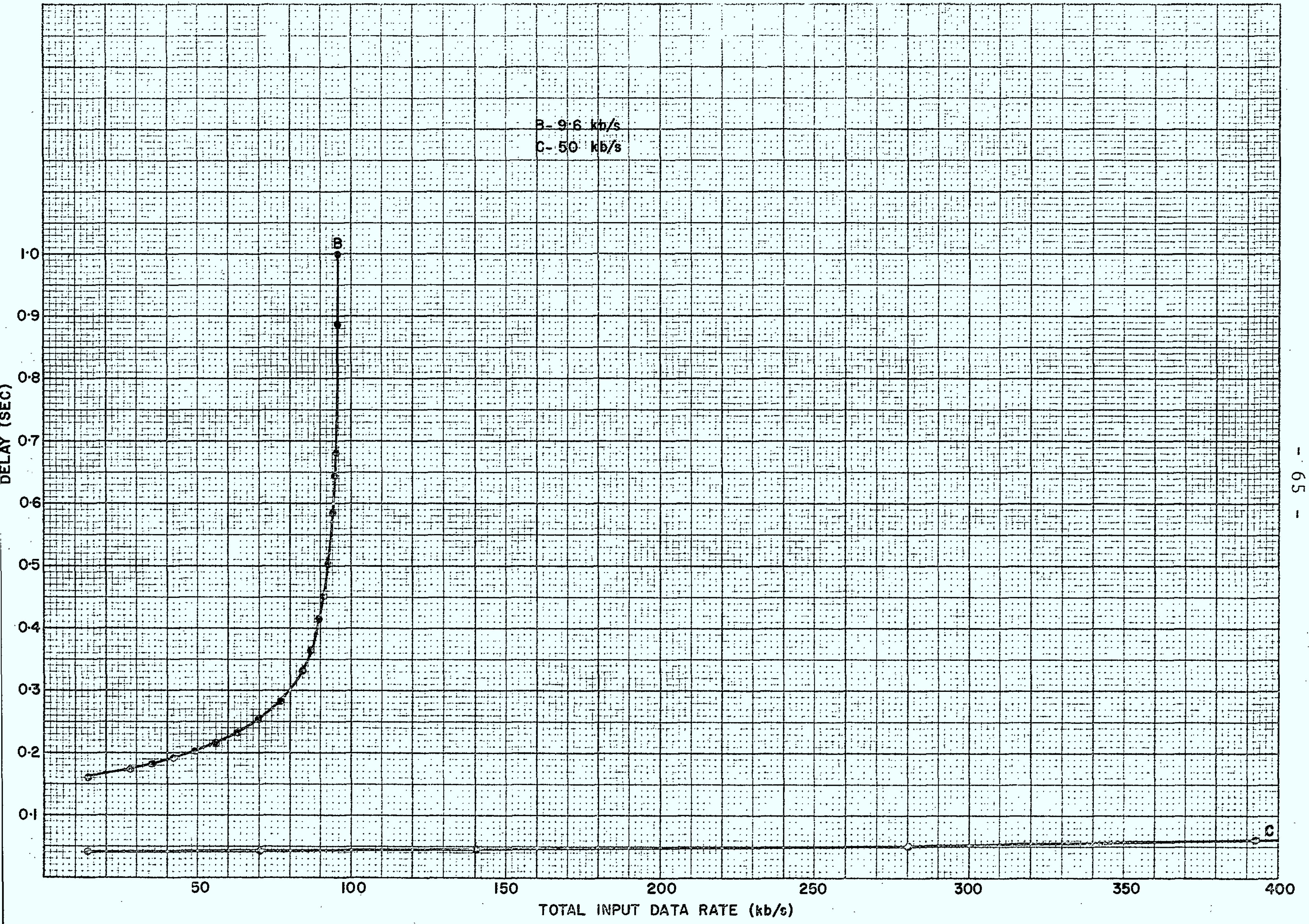
8 MONTREAL
9 QUEBEC
10 HALIFAX
N.C.U. (NODE CONTROL UNIT)
UNIVERSITY

NETWORK 3


B- 9·6 kb/s
C- 50 kb/s
B
C
DELAY (SEC)
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0·9
0·8
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0·6
0·5
0·4
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0·1
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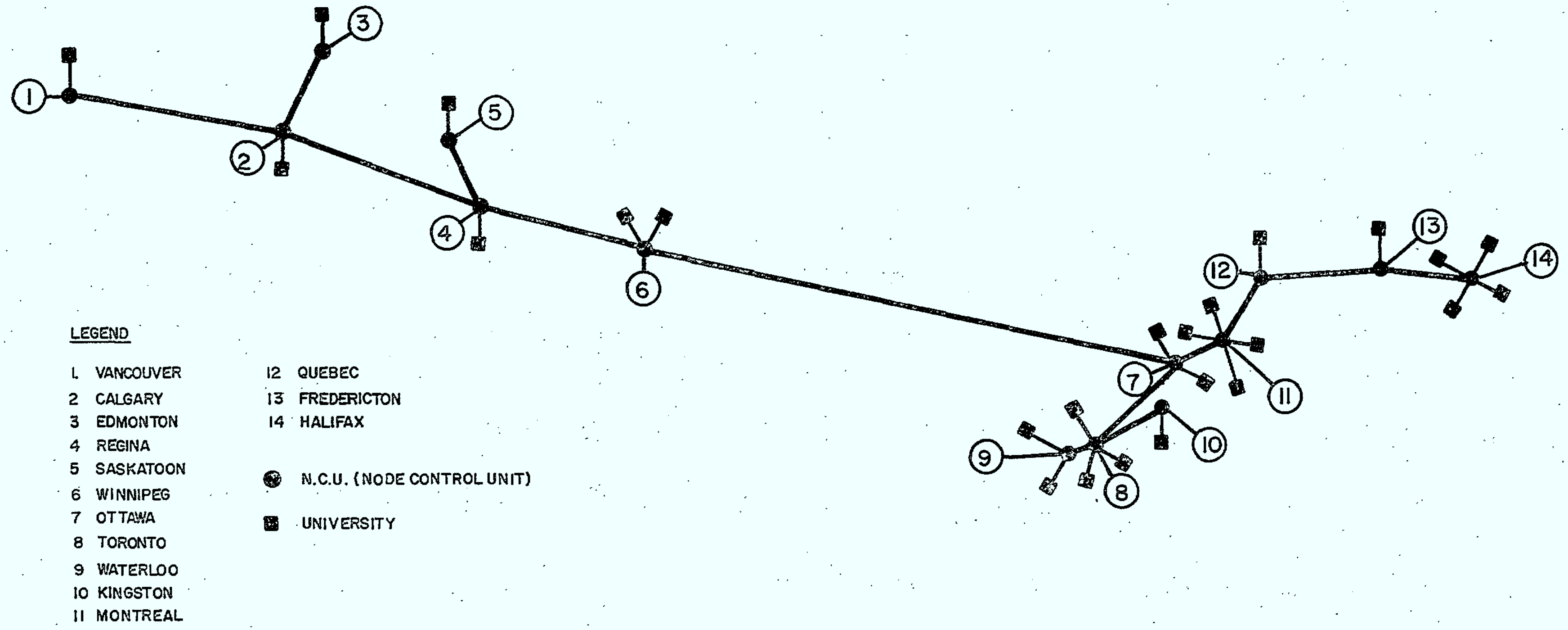
400
TOTAL INPUT DATA RATE (kb/s)

NETWORK 4



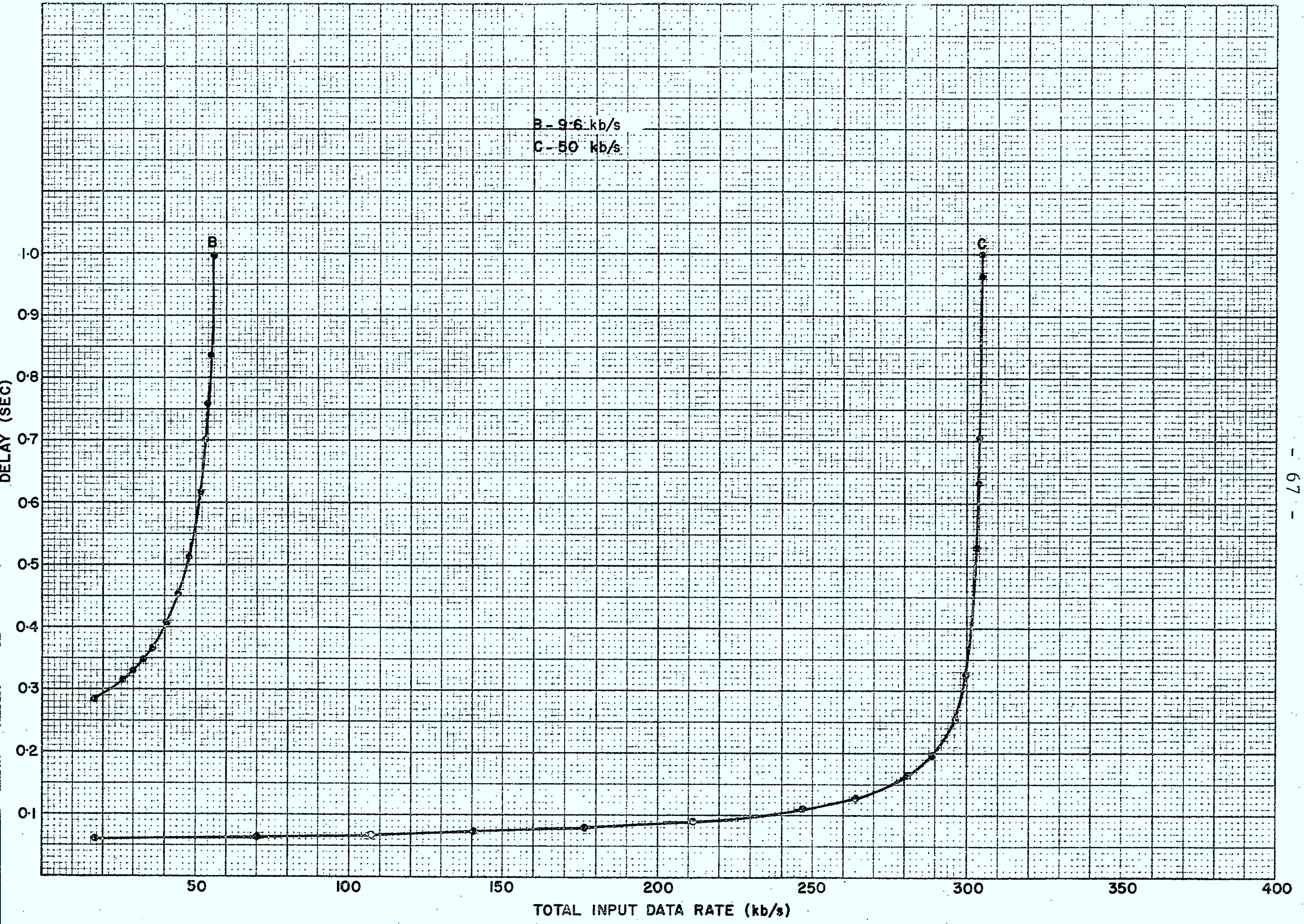
LEGEND

1 VANCOUVER
2 CALGARY
3 EDMONTON
4 REGINA
5 SASKATOON
6 WINNIPEG
7 OTTAWA
8 TORONTO
9 WATERLOO
10 KINGSTON
11 MONTREAL
12 QUEBEC
13 FREDERICTON
14 HALIFAX

● N.C.U. (NODE CONTROL UNIT)

▨ UNIVERSITY

NETWORK 4


B - 9·6 kb/s
C - 50 kb/s
B
C
DELAY (SEC)
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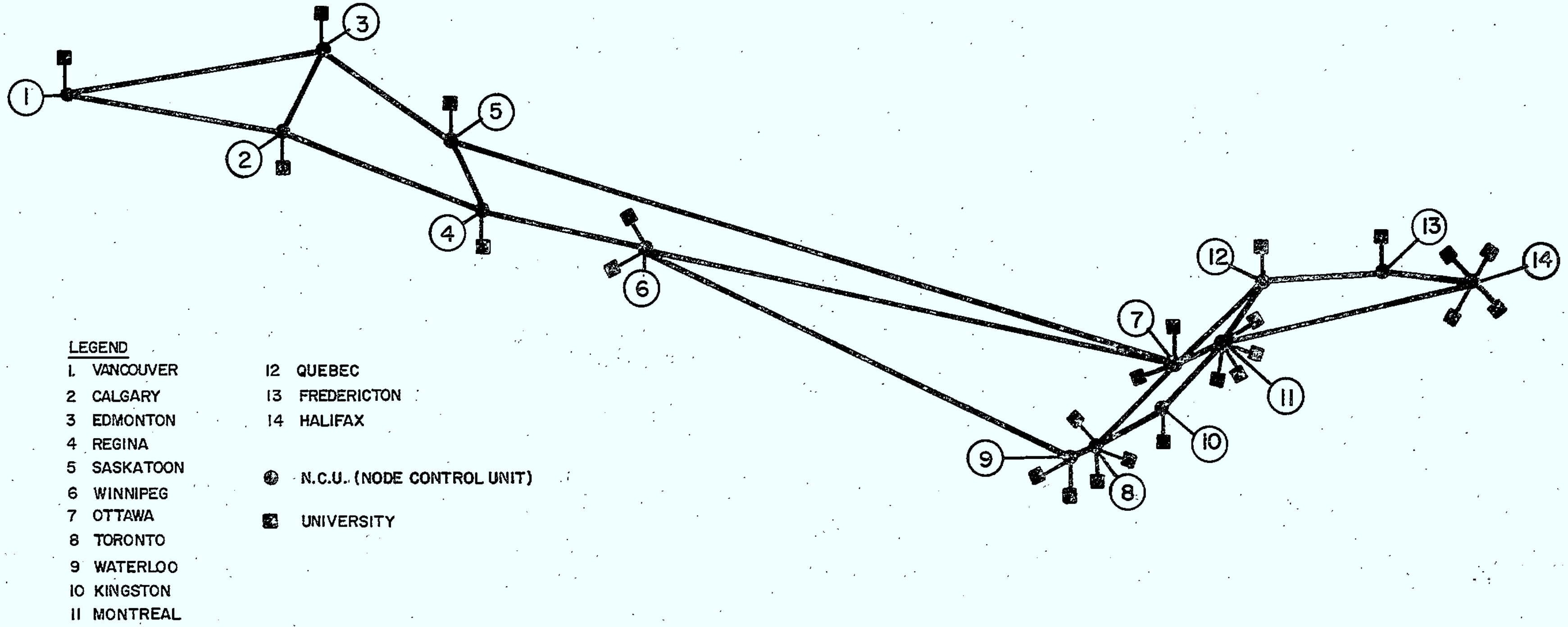
TOTAL INPUT DATA RATE (kb/s)

NETWORK 5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LEGEND
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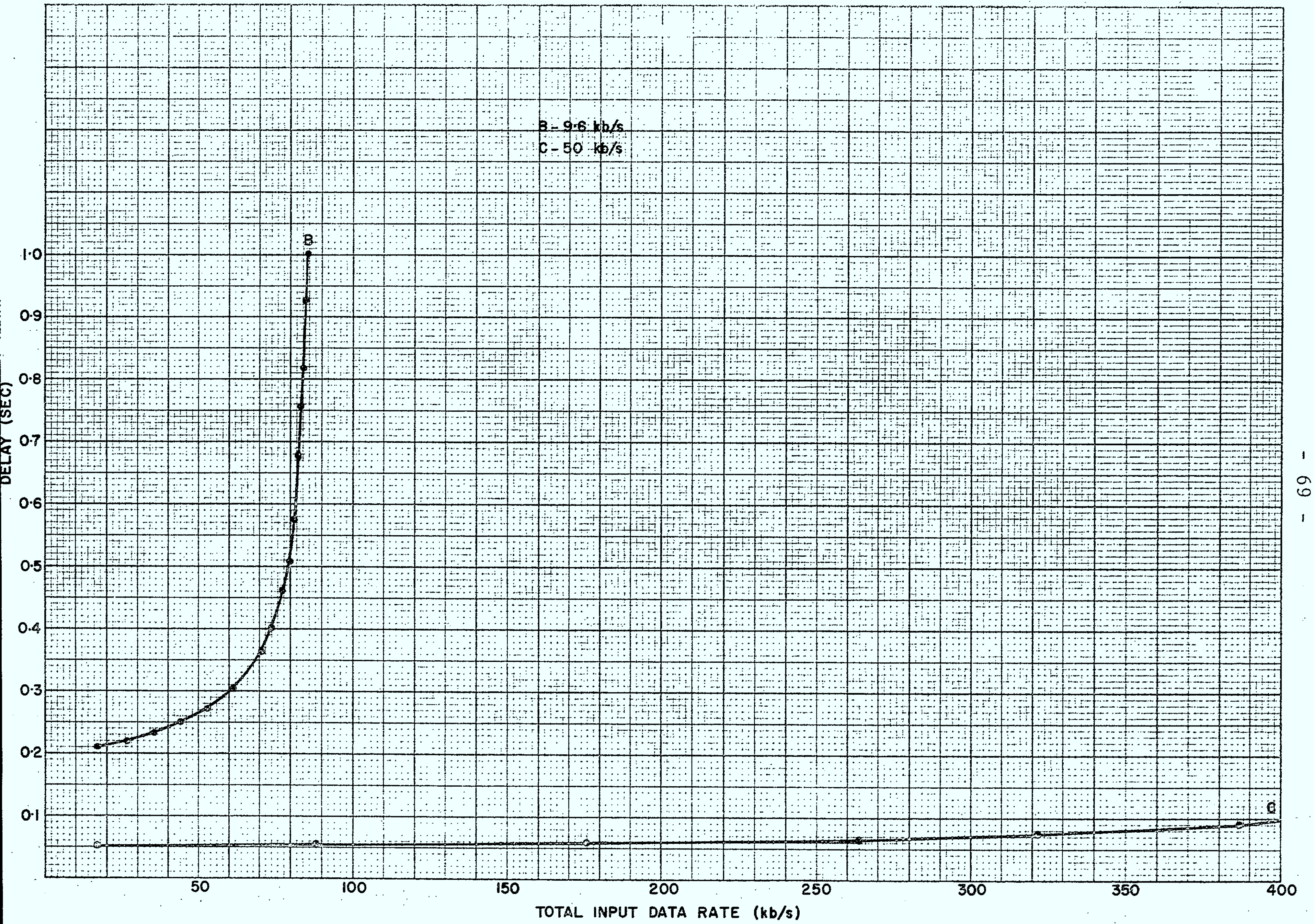
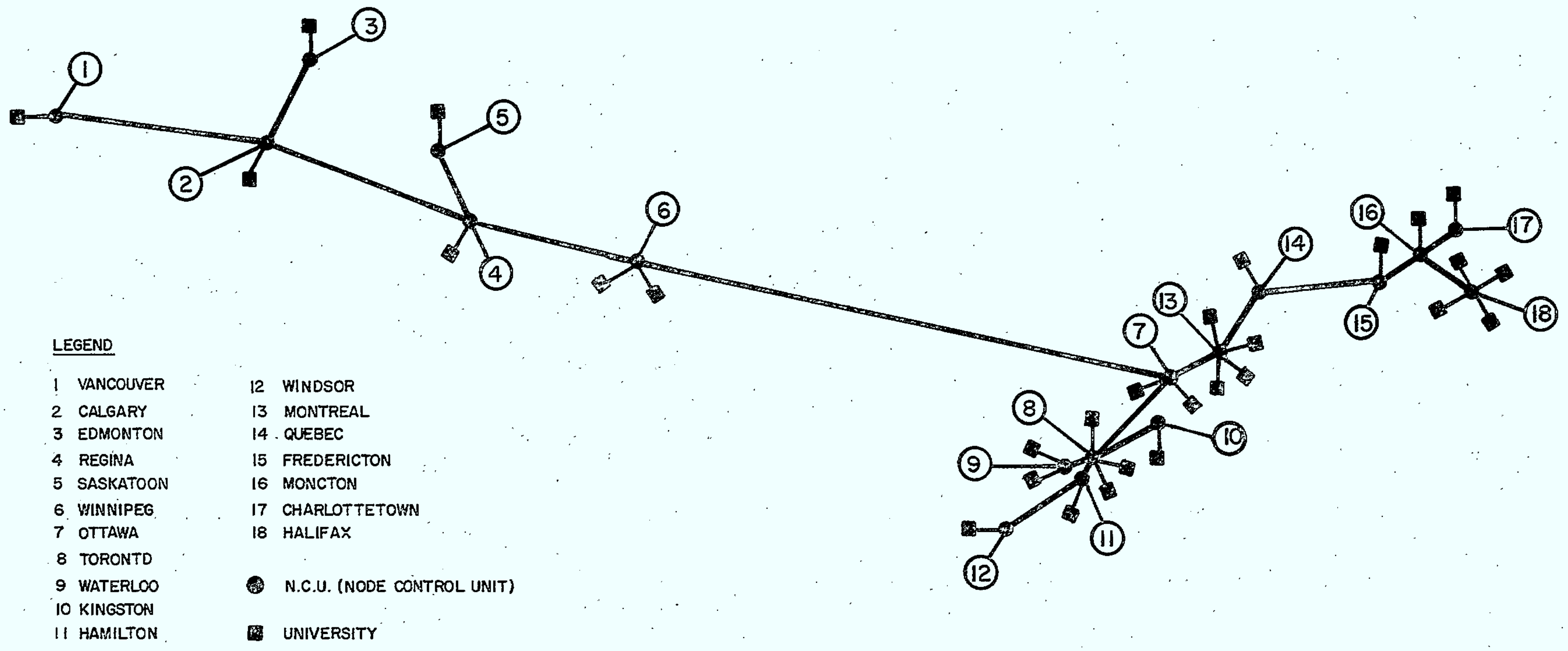
2 CALGARY
3 EDMONTON
4 REGINA
5 SASKATOON
6 WINNIPEG
7 OTTAWA
8 TORONTO
9 WATERLOO
10 KINGSTON
11 MONTREAL
12 QUEBEC
13 FREDERICTON
14 HALIFAX
● N.C.U. (NODE CONTROL UNIT)
▨ UNIVERSITY

NETWORK 5


B - 9·6 kb/s
C - 50 kb/s
B
C
DELAY (SEC)
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
50
100
150
200
250
300
350
400
TOTAL INPUT DATA RATE (kb/s)

NETWORK 6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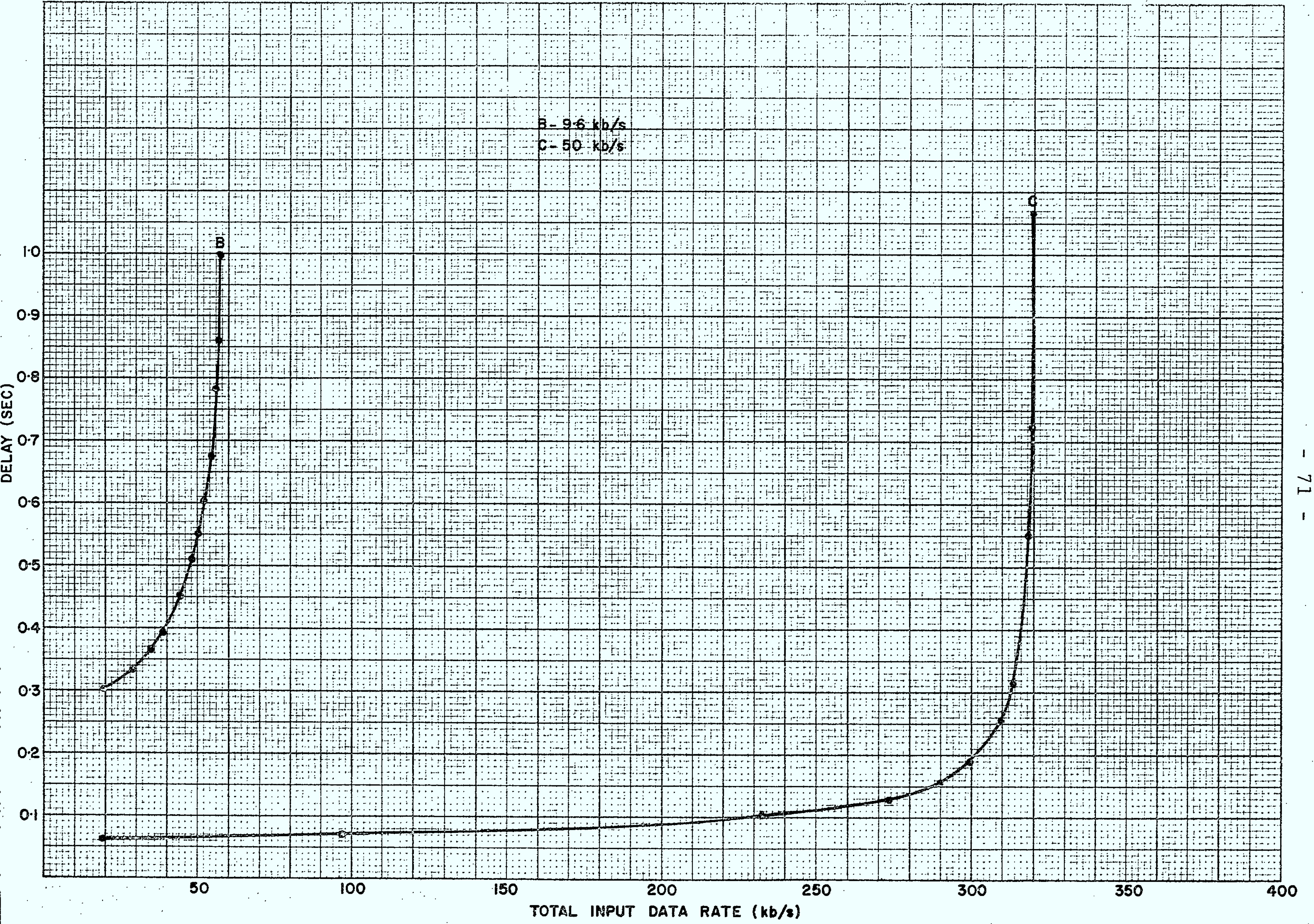
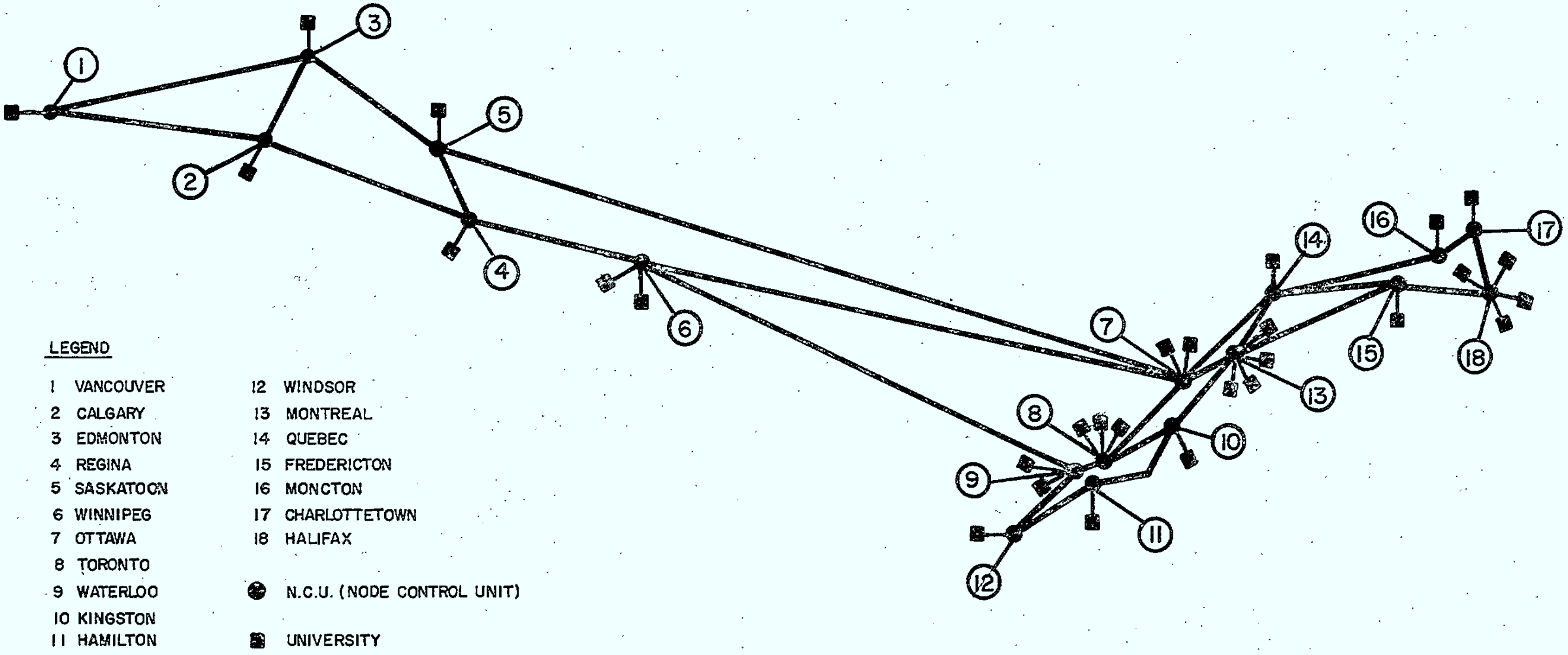
18
LEGEND
1 VANCOUVER
2 CALGARY
3 EDMONTON
4 REGINA
5 SASKATOON
6 WINNIPEG
7 OTTAWA
8 TORONTO
9 WATERLOO
10 KINGSTON
11 HAMILTON
12 WINDSOR
13 MONTREAL
14 QUEBEC
15 FREDERICTON
16 MONCTON
17 CHARLOTTETOWN
18 HALIFAX
● N.C.U. (NODE CONTROL UNIT)
▨ UNIVERSITY

NETWORK 6


B - 9·6 kb/s
C - 50 kb/s
B
C
DELAY (SEC)
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
50
100
150
200
250
300
350
400
TOTAL INPUT DATA RATE (kb/s)

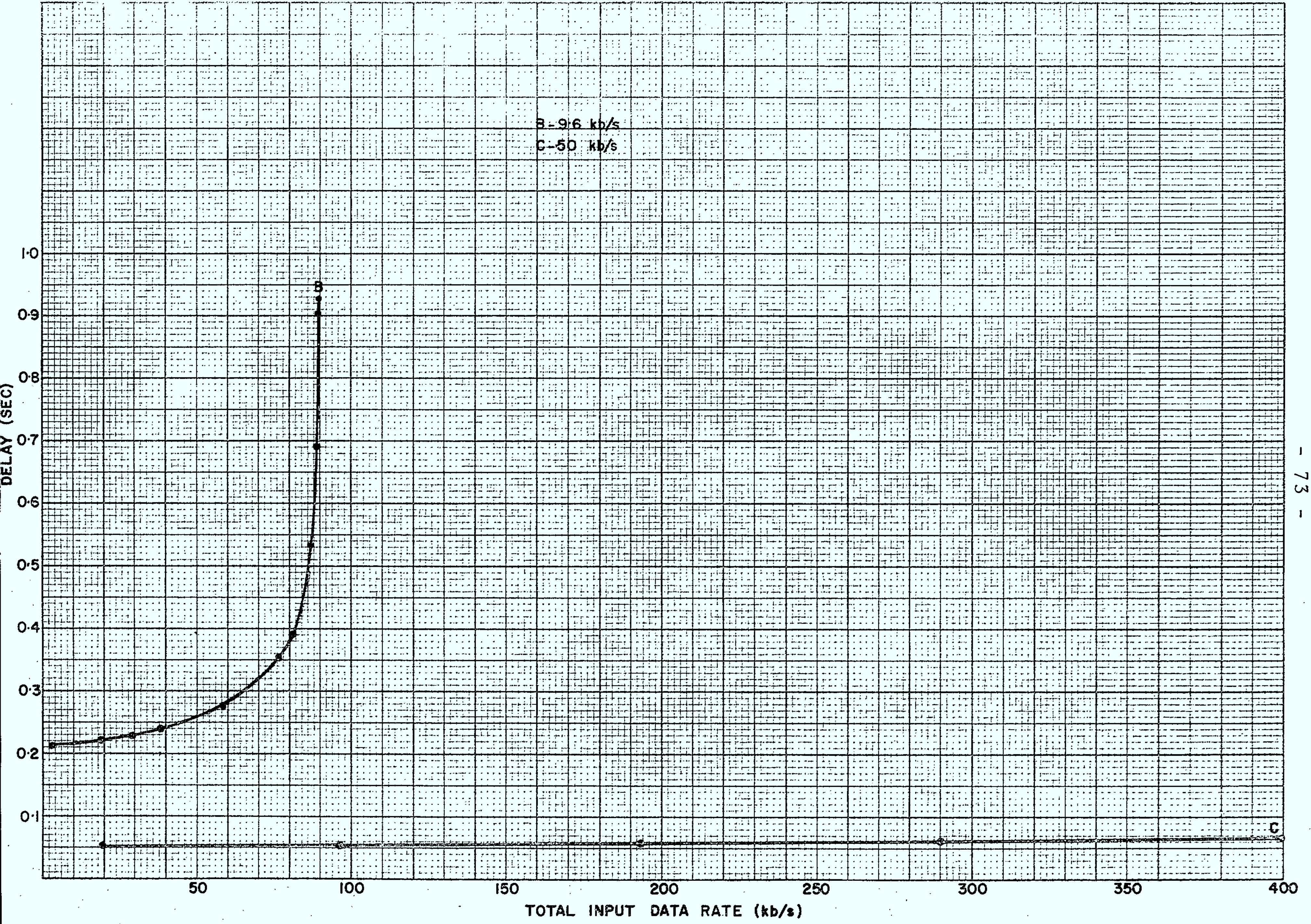
NETWORK 7



LEGEND

1	VANCOUVER
2	CALGARY
3	EDMONTON
4	REGINA
5	SASKATOON
6	WINNIPEG
7	OTTAWA
8	TORONTO
9	WATERLOO
10	KINGSTON
11	HAMILTON
12	WINDSOR
13	MONTREAL
14	QUEBEC
15	FREDERICTON
16	MONCTON
17	CHARLOTTETOWN
18	HALIFAX
●	N.C.U. (NODE CONTROL UNIT)
▨	UNIVERSITY

NETWORK 7


B-9·6 kb/s
C-50 kb/s
B
C
DELAY (SEC)
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
50
100
150
200
250
300
350
400
TOTAL INPUT DATA RATE (kb/s)

CHAPTER V

Detailed Simulation of a 10 Node Terrestrial Network

The following is a description of the simulation for Network 2 with 50 kb/s lines.

Average packet length = 640 bits

Average of (packet & acknowledgement) = 400 bits.

It contains;

$[C]$ = Branch Capacity Matrix (bits/sec)

$[T]$ = Traffic Matrix (bits/sec)

$[\lambda]$ = Matrix of the Average number of Messages/sec

$[\rho]$ = Network Utilization Matrix

$[A.D]$ = Average Delay Matrix in sec/message

BRANCH CAPACITY MATRIX

$$[C] = \begin{array}{c|cccccccccc}
 & (1) & (2) & (3) & (4) & (5) & (6) & (7) & (8) & (9) & (10) \\
(1) & 0. & 50000. & 50000. & 0. & 0. & 0. & 0. & 0. & 0. & 0. \\
(2) & 50000. & 0. & 50000. & 50000. & 0. & 0. & 0. & 0. & 0. & 0. \\
(3) & 50000. & 50000. & 0. & 50000. & 50000. & 0. & 0. & 0. & 0. & 0. \\
(4) & 0. & 50000. & 50000. & 0. & 50000. & 0. & 50000. & 0. & 0. & 0. \\
(5) & 0. & 0. & 50000. & 50000. & 0. & 50000. & 0. & 50000. & 50000. & 0. \\
(6) & 0. & 0. & 0. & 0. & 50000. & 0. & 50000. & 50000. & 0. & 0. \\
(7) & 0. & 0. & 0. & 50000. & 0. & 50000. & 0. & 0. & 0. & 0. \\
(8) & 0. & 0. & 0. & 0. & 50000. & 50000. & 0. & 0. & 50000. & 50000. \\
(9) & 0. & 0. & 0. & 0. & 50000. & 0. & 0. & 50000. & 0. & 50000. \\
(10) & 0. & 0. & 0. & 0. & 0. & 0. & 0. & 50000. & 50000. & 0.
\end{array}$$

$C(i,j)$ = Capacity of branch (i,j)

TRAFFIC MATRIX IN BITS/SEC.

$$
[T] = \begin{array}{rrrrrrrrrrr}
 & (1) & (2) & (3) & (4) & (5) & (6) & (7) & (8) & (9) & (10) \\
(1) & 0. & 966. & 1135. & 1820. & 1739. & 3126. & 1583. & 4625. & 1258. & 954. \\
(2) & 966. & 0. & 461. & 740. & 707. & 1271. & 644. & 1881. & 511. & 388. \\
(3) & 1135. & 461. & 0. & 870. & 831. & 1494. & 757. & 2210. & 601. & 456. \\
(4) & 1820. & 740. & 870. & 0. & 1333. & 2397. & 1214. & 3546. & 964. & 731. \\
(5) & 1739. & 707. & 831. & 1333. & 0. & 2289. & 1160. & 3387. & 921. & 698. \\
(6) & 3126. & 1271. & 1494. & 2397. & 2289. & 0. & 2085. & 6090. & 1656. & 1256. \\
(7) & 1583. & 644. & 757. & 1214. & 1160. & 2085. & 0. & 3084. & 839. & 636. \\
(8) & 4625. & 1881. & 2210. & 3546. & 3387. & 6090. & 3084. & 0. & 2450. & 1858. \\
(9) & 1258. & 511. & 601. & 964. & 921. & 1656. & 839. & 2450. & 0. & 505. \\
(10) & 954. & 388. & 456. & 731. & 698. & 1256. & 636. & 1858. & 505. & 0.
\end{array}
$$

The entries in this matrix are the amount of traffic in bits per second flowing along the arcs of the network.

MATRIX OF THE AVERAGE # OF MESSAGES/SEC.

$$[\lambda] = \begin{array}{ccccccccccc}
 & (1) & (2) & (3) & (4) & (5) & (6) & (7) & (8) & (9) & (10) \\
(1) & .000 & 1.509 & 25.375 & .000 & .000 & .000 & .000 & .000 & .000 & .000 \\
(2) & 1.509 & .000 & .721 & 9.598 & .000 & .000 & .000 & .000 & .000 & .000 \\
(3) & 25.375 & .721 & .000 & 15.078 & 19.802 & .000 & .000 & .000 & .000 & .000 \\
(4) & .000 & 9.598 & 15.078 & .000 & 15.722 & .000 & 19.509 & .000 & .000 & .000 \\
(5) & .000 & .000 & 19.802 & 15.722 & .000 & 9.287 & .000 & 29.495 & 10.547 & .000 \\
(6) & .000 & .000 & .000 & .000 & 9.287 & .000 & 25.143 & 17.291 & .000 & .000 \\
(7) & .000 & .000 & .000 & 19.509 & .000 & 25.143 & .000 & .000 & .000 & .000 \\
(8) & .000 & .000 & .000 & .000 & 29.495 & 17.291 & .000 & .000 & 3.828 & 10.901 \\
(9) & .000 & .000 & .000 & .000 & 10.547 & .000 & .000 & 3.828 & .000 & .789 \\
(10) & .000 & .000 & .000 & .000 & .000 & .000 & .000 & 10.901 & .789 & .000
\end{array}$$

The values of this matrix represent the average number of messages flowing on branch (i,j). Note that when an entry is zero, the corresponding term in the branch capacity matrix is also zero. i.e. no direct path exists between these two nodes.

NETWORK UTILIZATION MATRIX

$$[\rho] = \begin{array}{c|cccccccccc} & (1) & (2) & (3) & (4) & (5) & (6) & (7) & (8) & (9) & (10) \\ (1) & .000 & .012 & .203 & .000 & .000 & .000 & .000 & .000 & .000 & .000 \\ (2) & .012 & .000 & .006 & .077 & .000 & .000 & .000 & .000 & .000 & .000 \\ (3) & .203 & .006 & .000 & .121 & .158 & .000 & .000 & .000 & .000 & .000 \\ (4) & .000 & .077 & .121 & .000 & .126 & .000 & .156 & .000 & .000 & .000 \\ (5) & .000 & .000 & .158 & .126 & .000 & .074 & .000 & .236 & .084 & .000 \\ (6) & .000 & .000 & .000 & .000 & .074 & .000 & .201 & .138 & .000 & .000 \\ (7) & .000 & .000 & .000 & .156 & .000 & .201 & .000 & .000 & .000 & .000 \\ (8) & .000 & .000 & .000 & .000 & .236 & .138 & .000 & .000 & .031 & .087 \\ (9) & .000 & .000 & .000 & .000 & .084 & .000 & .000 & .031 & .000 & .006 \\ (10) & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .087 & .006 & .000 \end{array}$$

The entry (i,j) is a reflection of the use of that branch. The utilization factor was defined as:

$$\rho(i,j) = \frac{\text{Average number of bits flowing on branch } (i,j)}{\text{Capacity of branch } (i,j) \text{ in bits}}$$

$$\rho(i,j) = \frac{\lambda(i,j)}{\mu'.C(i,j)}$$

An entry $\rho(i,j)$ greater than one implies that the flow exceeded the capacity of the arc. (i,j)

AVERAGE DELAY MATRIX IN SEC/MESSAGES

$$\left[A.D\right] = \begin{array}{ccccccccccc}
 & (1) & (2) & (3) & (4) & (5) & (6) & (7) & (8) & (9) & (10) \\
(1) & .000 & .018 & .022 & .000 & .000 & .000 & .000 & .000 & .000 & .000 \\
(2) & .018 & .000 & .017 & .022 & .000 & .000 & .000 & .000 & .000 & .000 \\
(3) & .022 & .017 & .000 & .019 & .030 & .000 & .000 & .000 & .000 & .000 \\
(4) & .000 & .022 & .019 & .000 & .025 & .000 & .024 & .000 & .000 & .000 \\
(5) & .000 & .000 & .030 & .025 & .000 & .017 & .000 & .017 & .017 & .000 \\
(6) & .000 & .000 & .000 & .000 & .017 & .000 & .017 & .018 & .000 & .000 \\
(7) & .000 & .000 & .000 & .024 & .000 & .017 & .000 & .000 & .000 & .000 \\
(8) & .000 & .000 & .000 & .000 & .017 & .018 & .000 & .000 & .016 & .020 \\
(9) & .000 & .000 & .000 & .000 & .017 & .000 & .000 & .016 & .000 & .018 \\
(10) & .000 & .000 & .000 & .000 & .000 & .000 & .000 & .020 & .018 & .000
\end{array}$$

The entries of this matrix represent the average delay encountered by a message flowing on branch (i,j).

Total Average Delay = .0413 SEC/MES.

PART III

NETWORK COST COMPARISONS

Introduction

The emphasis of the Communication Studies Committee was directed towards the analysis of possible topological configurations for CANUNET. Some of these costs for terrestrial as well as for the hybrid networks given in this report are presented.

The terrestrial network costs in dollars per Megabits for 100% and 80% utilization are given in Tables 1, 2 and 3 for the various speed options and topologies *. For example, in a 50 kb/sec. 10 node single topology network, the cost of transmission for 1 megabit was found to be 13.9 cents for 80% utilization.

In all the cases (terrestrial as well as hybrid) the actual total communication cost for the network would have to include, other than the above communication line costs, the cost of the Node Control Unit plus maintenance.

In the case of ARPANET (*), a cost of 11¢/megabit was found. However, since it was felt the ARPA network was not expected to be always fully loaded to peak capacity, day and night, the actual cost was closer to 30¢/megabit based on a 36% average loading. This cost was for the communication lines only; it did not include the cost of the IMP nor maintenance.

In case of CANUNET, for 80% utilization, the communication line cost can go as high as 24.5¢/megabits for network 7 (Fig.1). Looking ahead, users of the network could be charged as a function of traffic initiated at a node based on the total usage of the network.

(*) "Topological Analysis and Design of CANUNET*; by J. deMercado, R. Guindon, J. da Silva, and M. Kadoch. January 1972.

(*) "A Forward Look"; by Larry Roberts, June 1971.

If a satellite is used to generate a hybrid realization then, the total cost of CANUNET will be the summation of the cost of satellite and terrestrial facilities. Table 4*) is the total annual renting charge as supplied by Telesat for a full RF channel.

This channel could accommodate up to 70 carriers for the 50 kb/sec. lines and 140 carriers for the 9.6 kb/sec. lines. Table IV should therefore be read by keeping in mind that the:

(Number of stations per network) x (Number of networks)
$\leq$ 70 <u>for the 50 kb/sec. lines</u>,

and $\leq$ 140
<u>for the 9.6 kb/sec. lines</u>.

This table also indicates that a cost of $3,000,000 per year has been established as the minimum rental for an RF channel and a complement of earth station equipment. To this cost must now be added the yearly terrestrial costs. For example, using the topology given in Fig. 2 for the 18 node 6 earth station network the yearly terrestrial cost would be $711,300. Again this is an approximate cost and could change when the exact topology is known.

It should be noted that a more detailed engineering analysis would be required to arrive at the most effective overall system configuration.

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*) see page 87

Terrestrial Networks (See Part II)

TABLE I

Speed of line	4.8 kb/sec.		
NETWORK	Total Input Data Rate (kb/sec.)	Cost ($/Mbits)	
		100% Utilization	80% Utilization
1	11	.506	.632
2	45	.241	.301
3	36	.233	.290
4	3.5	2.038	2.55
5	23	0.555	.694
6	1	8.779	10.97
7	25	.607	.759

Terrestrial Networks (See Part II)

TABLE 2

Speed of line NETWORK	9.6 kb/sec.		
	Total Input Data Rate (kb./sec.)	Cost ($/Mbits)	
		100% Utilization	80% Utilization
1	49	.156	.195
2	108	.132	.165
3	92	.119	.149
4	47	.215	.269
5	79	.218	.272
6	48	.263	.329
7	86	.246	.308

Terrestrial Networks (See Part II)

TABLE 3

Speed of line NETWORK	50 kb/sec.		
	Total Input Data Rate (kb/sec.)	Cost ($/Mbits)	
		100% Utilization	80% Utilization
1	304	.111	.139
2	591	.130	.163
3	508	.121	.151
4	302	.133	.166
5	455	.182	.225
6	317	.142	.178
7	477	.196	.245

TABLE 4

50 or 9.6 kb/s

TOTAL ANNUAL CHARGE $ MILLION	ANNUAL CHARGE PER NETWORK $ MILLION

	NUMBER OF NETWORKS													
NO. OF STATIONS PER NETWORK	1	2	3	4	5	6	8	10	15	20	25	30	35	70
2	3 3	3 1.5	3 1.0	3 0.75	3 0.6	3 0.5	3 0.38	3.08 0.31	3.55 0.24	4.03 0.20	4.50 0.18	4.98 0.17	5.45 0.16	8.78 0.13
3	3 3	3 1.5	3 1.0	3 0.75	3 0.6	3.10 0.52	3.41 0.43	3.73 0.37	4.52 0.30	5.31 0.27	6.10 0.27	6.89 0.23	7.68 0.22	
4	3 3	3 1.5	3 1.0	3.09 0.77	3.32 0.66	3.56 0.59	4.02 0.50	4.48 0.45	5.64 0.38	6.79 0.34	7.95 0.35	9.10 0.30	10.26 0.29	
5	3 3	3 1.5	3.14 1.05	3.45 0.86	3.77 0.75	4.08 0.68	4.71 0.59	5.34 0.53	6.92 0.46	8.49 0.43	10.01 0.40			
6	3 3	3.03 1.5	3.44 1.15	3.85 0.96	4.27 0.85	4.68 0.78	5.50 0.69	6.32 0.63	8.38 0.56	10.43 0.52				
7	3 3	3.26 1.63	3.78 1.29	4.29 1.07	4.81 0.96	5.32 0.89	6.35 0.79	7.38 0.74	9.96 0.66	12.53 0.63				
8	3 3	3.52 1.76	4.15 1.38	4.78 1.20	5.41 1.08	6.04 1.01	7.30 0.91	8.56 0.86	11.71 0.78	14.86 0.74				

50 and 9.6 kb/s ← → 9.6 kb/s

NETWORK 7

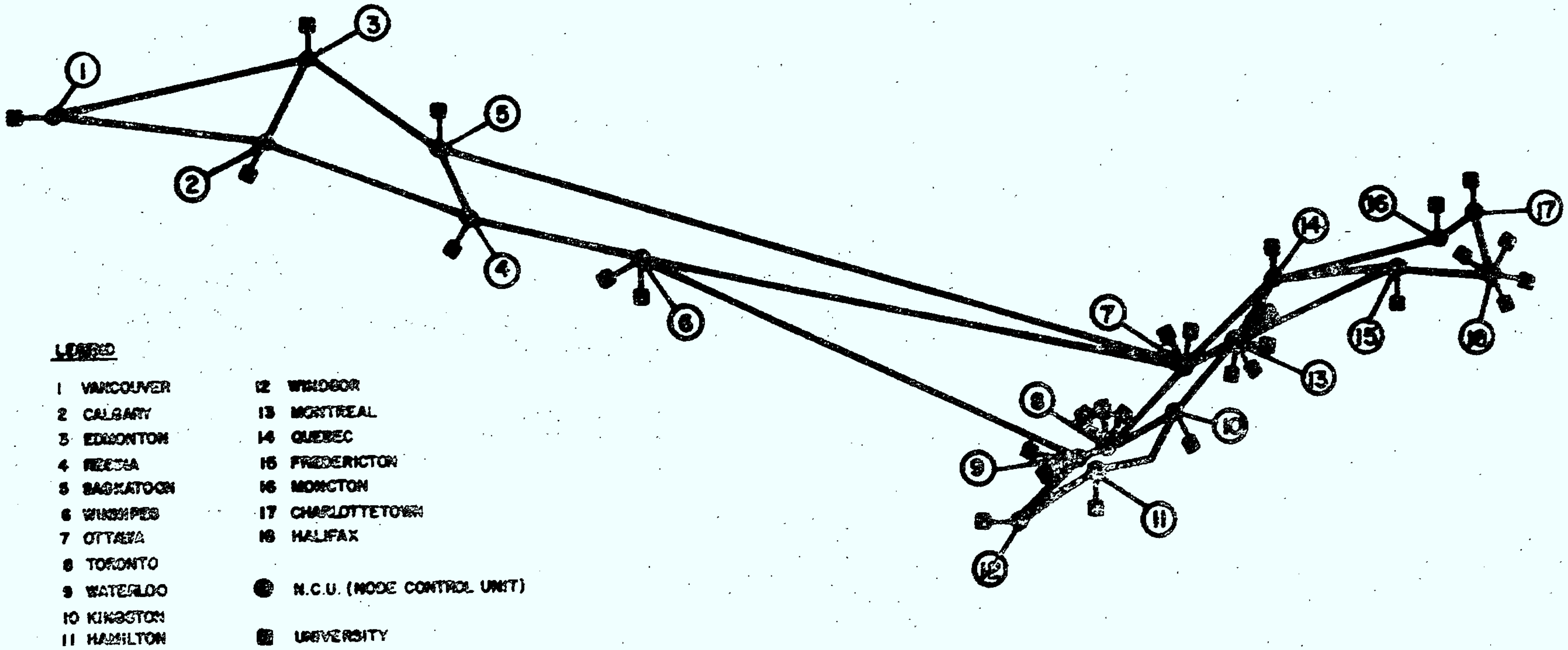

Fig. 1

NOD 18 SAT 6

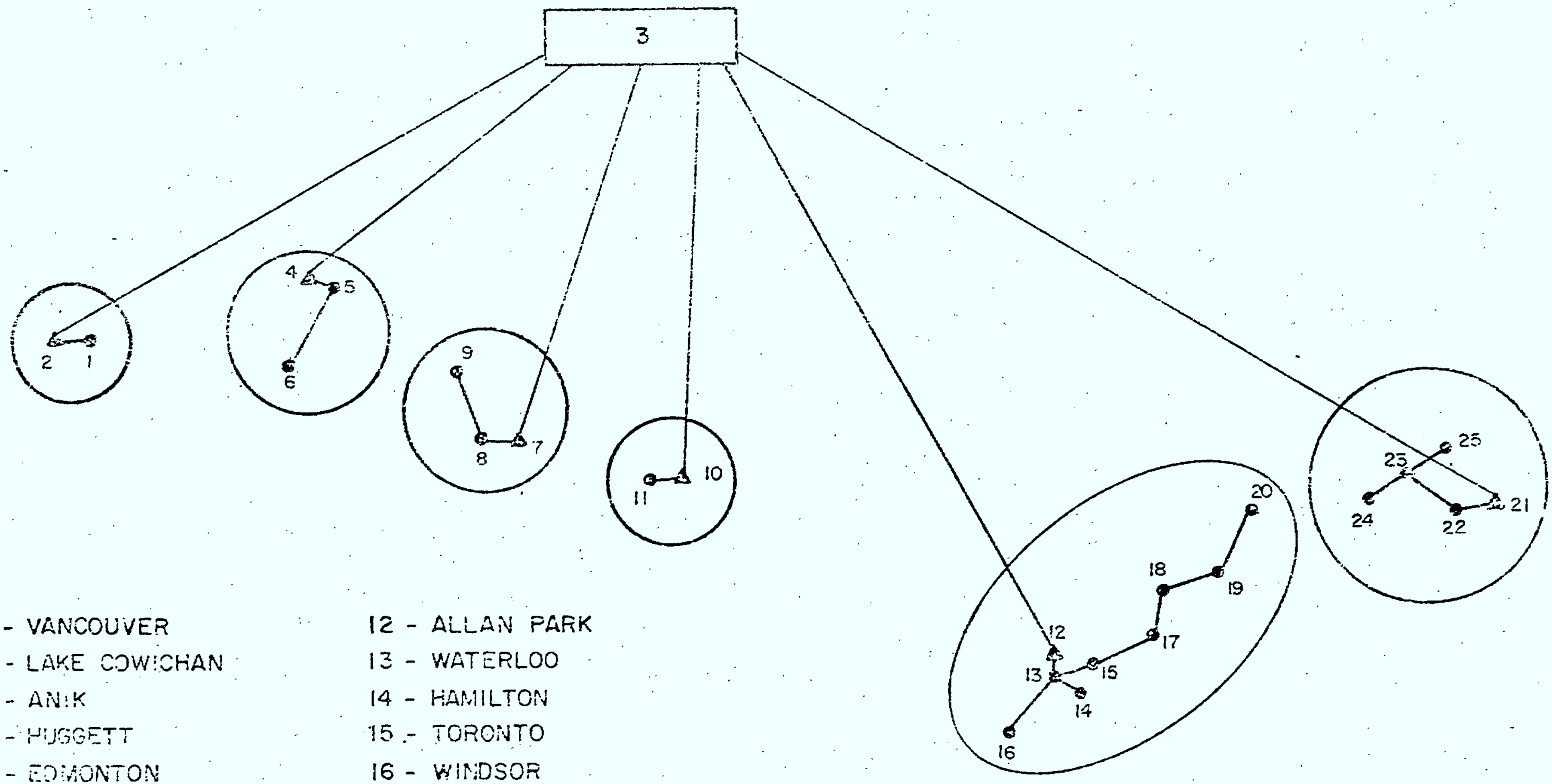

Fig. 2

1 - VANCOUVER
2 - LAKE COWICHAN
3 - ANIK
4 - HUGGETT
5 - EDMONTON
6 - CALGARY
7 - QU'APPELLE
8 - REGINA
9 - SASKATOON
10 - GRAND BEACH
11 - WINNIPEG

12 - ALLAN PARK
13 - WATERLOO
14 - HAMILTON
15 - TORONTO
16 - WINDSOR
17 - KINGSTON
18 - OTTAWA
19 - MONTREAL
20 - QUEBEC
21 - HARRIETSFIELD
23 - HALIFAX

23 - MONCTON
24 - FREDERICTON
25 - CHARLOTTETOWN

● N.C.U. (NODE CONTROL UNIT)

▲ GROUND STATION

CHAPTER VI

Terrestrial Costs for Hybrid Network

Table 5 is the yearly cost for the terrestrial networks which must be added to the $3,000,000 per year established by Telesat. This would be the total cost for the satellite/terrestrial network.

As shown in Table 4 *) this yearly rental cost of ANIK could go down if shared with other customers. For example, if 3 organizations share 7 stations per network then, the yearly rental cost of ANIK would be $1.29 million. This therefore suggest that the use of satellite will only become attractive when more than one or two organizations or networks share in the rental of an ANIK channel.

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*) see page 87

TABLE 5

(Yearly Terrestrial Costs)

Speed of lines Network	4.8 kb/sec.	9.6 kb/sec.	50 kb/sec.
NOD 10 SAT 4 Topology #1	$ 133,650	$ 193,650	$ 558,600
NOD 10 SAT 4 Topology #2	$ 206,200	$ 290,200	$ 905,700
NOD 10 SAT 5 Topology #1	$ 122,800	$ 182,800	$ 484,200
NOD 10 SAT 5 Topology #2	$ 195,400	$ 279,400	$ 831,300
NOD 10 SAT 5 RIVIERE ROUGE)	$ 122,500	$ 182,500	$ 482,700
NOD 10 SAT 7	$ 102,400	$ 162,400	$ 344,100
NOD 14 SAT 6	$ 152,300	$ 236,300	$ 546,300
NOD 18 SAT 4	$ 222,300	$ 330,300	$ 848,700
NOD 18 SAT 6	$ 198,800	$ 306,800	$ 711,300

Conclusions

The results obtained in this study are based on the analysis of computer-communication network performance using methods from queueing and network flow theory.

The model used for the hybrid network simulation considered an earth station of the Satellite system as an IMP or an NCU (node control unit). If this function is not required at those stations then the total average message delay for the considered network would be less. The simulation results were given in terms of performance graphs where the minimum delays were found to be between 210 ms and 290 ms *). As was stated in the report those results were the worst case situation.

The authors hope that the analysis results presented in this report will allow the Advisory Committee to speedily settle on the best Topology for CANUNET.

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*) A minimum of 210 ms was found for NOD 18 SAT 4 using 50 kb/s terrestrial lines, and a minimum of 290 ms was found for NOD 10 SAT 7 using 50 kb/s terrestrial lines.

APPENDIX A

Introduction

There exists other network configurations which have not yet been considered for CANUNET. Among those, the loop or ring system is a possible alternative. This appendix briefly describes this type of network.

Loop Transmission Networks

Recently, several papers appeared in the litterature (1,2,3,4,5) proposing data communication networks where the users were connected in a ring or loop topology. The loop-transmission system consists of a closed communication loop composed of a System Controller, terminals where traffic enters and leaves the loop, and gateways which provide a connection between two loops.(see fig.A.1) A user at some terminal inputs the message he wants to send, the terminals breaks the message into fixed size packets, supplies it with a header which contains source and destination addresses, and according to a scheduling algorithm feeds the packets into the line. The traffic flows in one direction around the loop from terminal to terminal. At each terminal, the address of a packet is examined to determine whether the packet's destination is at that particular terminal.

In order to explain the mechanism of multiplexing packets on and off the line, it is helpful to draw an analogy between a loop and a conveyor belt.(see fig. A.2) Time slots, into which packets may be placed, circulate around the loop. At the beginning of each time slot is a marker which indicates whether the time slot is empty or full, therefore a terminal can use an empty slot to feed its own packet on the line. If the slot is full a packet trying to enter the loop waits until an empty slot arrives at the particular terminal. In other words, the traffic already in transmission has priority over the traffic seeking entrance into the loop.

The functions of the System Controller are twofold;

a) synchronization of the ring.
b) prevention of traffic buildup.(a packet passing the System Controller twice, is destroyed)

The gateways provide a connection between two loops. The behaviour of these gateways is in some sense, the same as the terminal's with the difference that the packets are now passing from one loop to another.

As mentioned earlier, a packet has to wait in a terminal or gateway buffer if the loop is busy, and this waiting time is, of course, one of the most important figure of merit of any computer network.

Calculations of the average message delay were made by Hayes and Sherman(5) for a 10, 50 and 100 terminal loops and the results obtained show that the average message delay is quite small for a wide range of line loadings.

Loops of the type previously described are particularly suited to environments where terminals are clustered, but they could be used for provincial or national networks.(see fig.A.3) However, the major obvious drawback is the fact that the series nature of the loop can cause the failure of the entire loop if one of the terminals fails. A detailed study should be conducted to determine the cost of a loop vis-a-vis the cost of a distributed network like the one initially proposed for CANUNET.

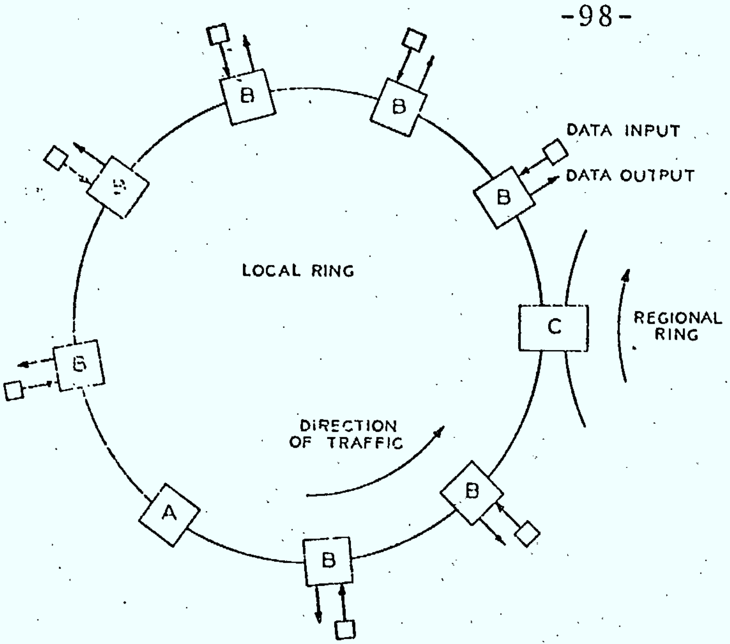

fig. A.1 - A- System Controller,
B- Terminal,
C- Gateway

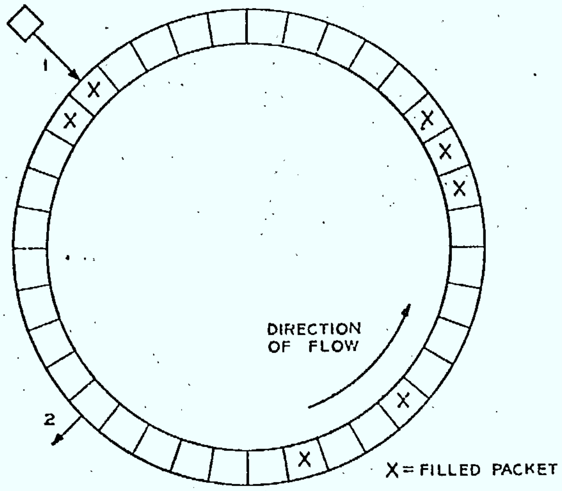

fig. A.2 - Packets enter at 1 and leave at 2.

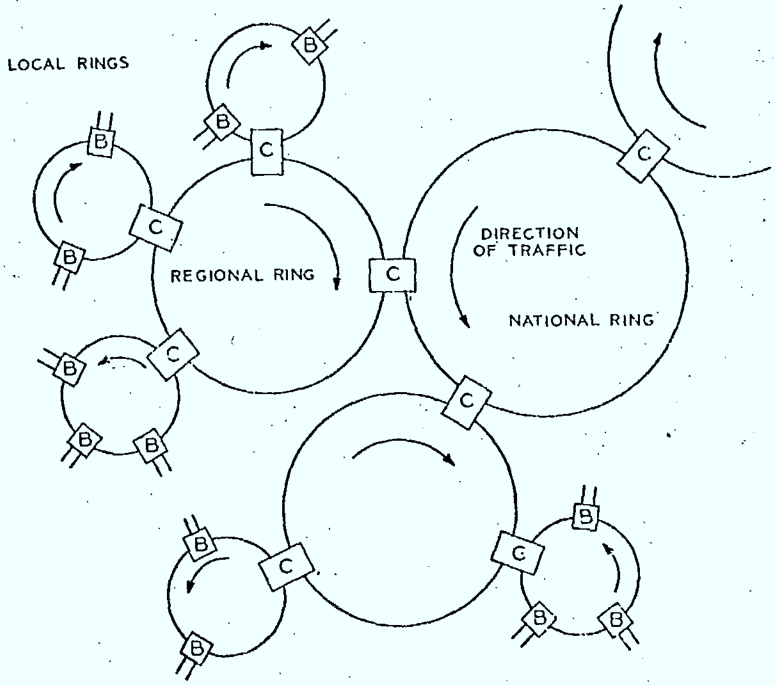

fig. A.3 - General Loop Network

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APPENDIX B

Introduction

So far, the design of CANUNET has been based upon the concept of message switched network. It was felt that more serious consideration should be given to the line switched network. This appendix explores this possibility.

Discussion of Message Switching versus Circuit Switching

Historically, two basic approaches have been utilized to switch data communications traffic. These two popular techniques are the space division switching or line switching and the message switching. Recently, with the need for faster and faster response times in computer networks, the second approach (message switching) appeared to be more attractive because the time delays encountered by a message flowing in the network were almost negligible compared to the time delays on a line switching network. This was due to the fact that the telephone network was originally designed to carry voice traffic.

More recently, several studies (1,2,3,4,5,6,7) were conducted in order to determine how a special line switched network separate from the telephone network, would behave when used only for data communications.

What follows is a resumé of the paper "Comparison of Switched Data Networks on the Basis of Waiting Times", by E. Post & F. Closs. The article evaluates the network response time when line and message switching are used. For a message switched, the response time is defined as the elapsed time between the moment a message enters the network and the moment the message arrives at destination; for a line switched network it is defined as the time between the moment a transmission service is requested and the moment the message arrives at destination. In a message switched environment, users have access to the network at any time but the messages sent are queued up at each node control unit. In a line switched network the request for service is queued up until a path from origin to destination is established, the message or messages are then sent without incurring any queuing delay. It should be noted that the processing time to set up a connection in a line switched network could be quite large if the switching exchange is of the electro-mechanical type. With the new electronic switching exchanges already in existence, one can neglect the processing time to set up a connection.

Waiting Time Evaluation

Figure B.1 represents two simplified network models.

In the line switched model, the terminals store the messages until one of the R channels of capacity C_o becomes free. The request for service is served at the switching exchange possibly on a first -come first-served basis. Once a message is sent no queuing delays are encountered; the only delay being the transmission time necessary to send a given message.

Therefore the total delay is given by:

$$T_{dls} = T_t + T_{qls} \qquad \text{..........(1)}$$

where;

T_{dls} = total delay (line switched case)

T_t = transmission time or time it takes to send a message over a channel with capacity C_o.

T_{qls} = total request for service queueing time.

In the message-switched model the terminals send the messages through the local loop of capacity C_o to the node control unit where the message is stored. Once the message enters service (messages are served in order of arrival), it is sent to the next node control unit over a high speed line of capacity $C = RC_o$ and then delivered to the destination terminal over a channel of capacity C_o. Therefore, the total delay is given by:

$$T_{dms} = T_t + T_{qms} + \frac{Tt}{R} + T_t \text{ ....(2)}$$

where:

T_{dms} = total delay (message-switched case)

T_t = transmission time or time it takes to send a message over a channel with capacity C_o.

T_{qms} = total queueing time.

It is now possible to compare equations (1) and (2), on the basis of the queueing time by disregarding the transmission time.

The queueing time T_{qms} for the message switched case is easily found by assuming that the arrivals of messages form a Poisson process and that the message lengths are exponentially distributed. Furthermore, messages are served on a first-in first-out basis by a single server. This is the well-known M/M/1 queue model and therefore the average queueing time is found to be;

$$T_{qms} = \frac{\rho . Ts}{1-\rho}$$

where;

T_s = average service time on a channel whose capacity is $C = RC_o$.

ρ = utilization factor

therefore, if $\frac{1}{\mu}$ is defined as the average message length;

$$T_s = \frac{1}{\mu} \quad \frac{1}{C} = \frac{1}{\mu RC_o}$$

$$\rho = \frac{\lambda}{\mu C} = \frac{\lambda}{\mu RC_o}$$

where λ represents the average number of messages.

Finally;

$$T_{qms} = \frac{\lambda/\mu C}{\mu C - \lambda} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

With the same assumptions, the queueing time for the line switched case when R servers are present is given by; (*)

$$T_{qls} = \frac{1}{R}\,\frac{P(>o)}{(1-\rho)} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

---

* Equation (4) can be found on page 116 of "Elements of Queueing Theory", by T.L. Saaty.

where $P(>o)$: the probability that a request for service has to wait in the queue is the well-known ERLANG's C formula given by;

$$P(>o) = \frac{(R\rho)^R}{R!\ (1-\rho) \sum_{n=o}^{R-1} \frac{(R\rho)^n}{n!} + (R\rho)^R} \quad .....(5)$$

The service time T_s in equation (4) is R times smaller than the service time found for the message switched case , that is;

$$T_s = \frac{1}{\mu C} \cdot \frac{1}{R}$$

Dividing equation (4) by equation (5), the relation between the two queueing times is found to be;

$$\frac{T_{qms}}{T_{qis}} = \frac{\rho}{P(>o)} \quad ....(6)$$

From equation (6), several curves can be drawn by varying R, the number of subchannels of capacity C_o.

For R = 1, the numerator and denominator of the right hand side of equation (6) become identical. Therefore the queueing times for the message switched and line switched case are the same, as a function of ρ.

For R = 2, the following relation is obtained;

$$\frac{T_{qms}}{T_{qls}} = \frac{1 + \rho}{2\rho} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

From equation (7), it can clearly be seen that the average queueing time in the message switched case for small line loadings can be several times larger than the average queuing time for the line switched case.

As the line loading approaches, full utilization the queueing times for the two cases become identical.

It can easily be shown that for higher values of R, the value of equation (6) becomes larger and larger for the same line loading.

The preceeding results were derived for a fully connected network i.e a network where a direct path exists between any two switching exchanges but these results can be extended to any network topology. Figure B.2 represents a typical relation between the two queueing times. It can be seen that depending on the line utilization, the queueing time for the message switched case can be smaller or larger than the queueing time for the line switched case.

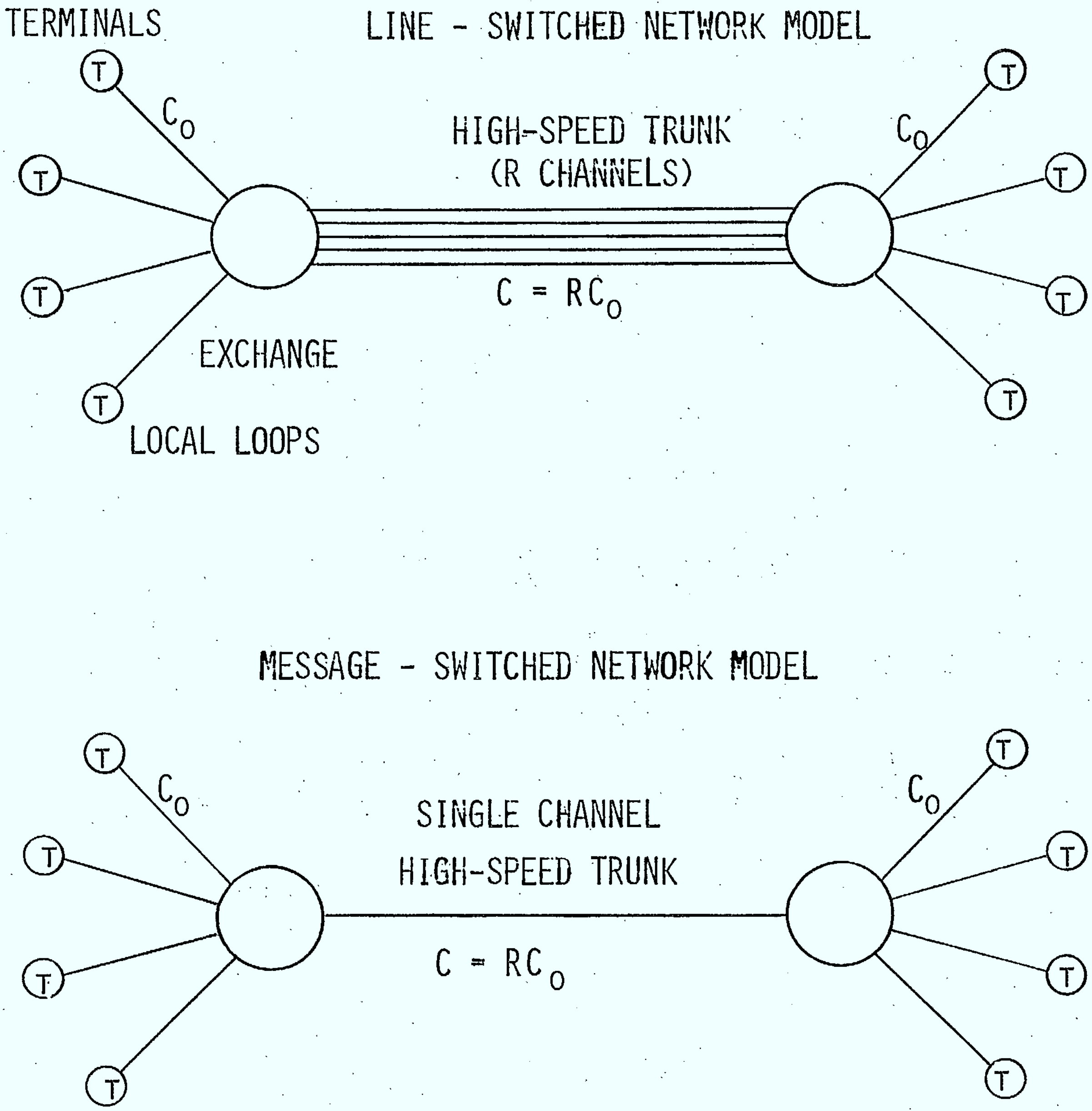

Fig. B.1 Simplified equivalent network models for message-switched operation.

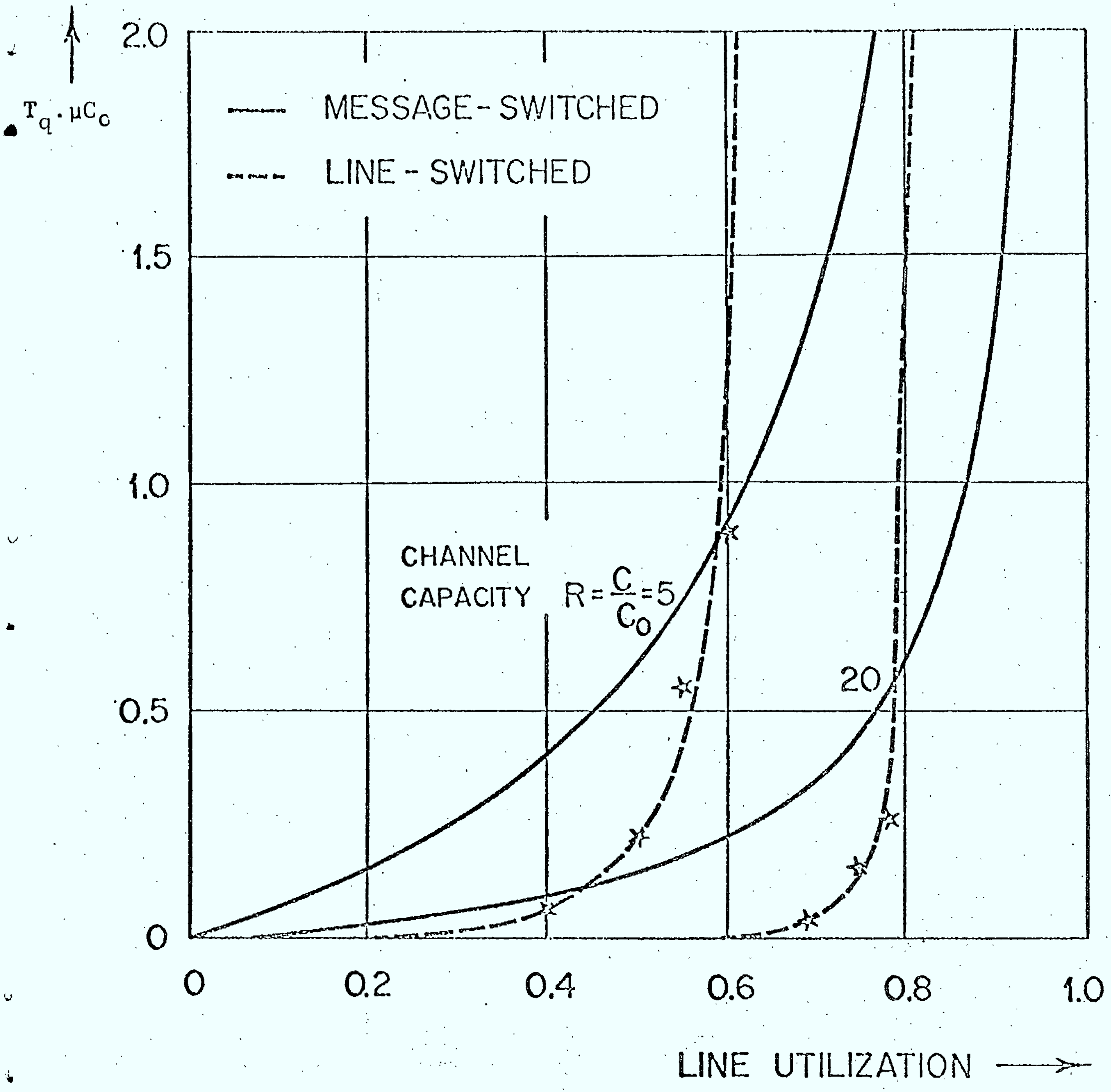

Fig. B.2 Average queuing times for line-switched and message-switched operation in a three-link network model.

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