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PROGRAM IN INFORMATION POLICY

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COST COMPARISON OF COMPETING LOCAL DISTRIBUTION SYSTEMS FOR COMMUNICATION SATELLITE TRAFFIC

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Abstract

The purpose of this paper is to describe the boundaries of market areas which favor various means for distributing communications satellite traffic. The distribution methods considered are: control earth station with cable access, rooftop earth stations, earth station with radio access, and various combinations of these methods.

The method of comparison is to determine the least cost system for a hypothetical region described by number of users and the average cable access mileage. The region is also characterized by a function which expresses the distribution of users.

The results indicate that the least cost distribution is central earth station with cable access for medium to high density areas of a region, combined with rooftop earth stations or (for higher volumes) radio access for remote users.

Introduction

Technological improvements increasing satellite capacity and lowering costs are likely to continue, implying that the long haul portion of telecommunications costs will steadily assume less importance. This paper focuses on least cost configurations for local distribution of satellite traffic, which is likely to account for an ever increasing portion of telecommunications cost.

The local distribution problem is non-trivial because of the different approaches and technical alternatives for meeting demand that are available. In general, existing common carriers favor use of large earth stations and local distribution provided by existing facilities. Current plans call for only five Western Union earth stations and only seven joint AT&T/GTE earth stations. New entrants, on the other hand, prefer to avoid distribution over existing facilities, instead relying on smaller units which can be placed on customer premises. The latter approach is exemplified by the Satellite Business Systems (SBS) proposal for small rooftop earth stations. In the SBS case, the local distribution cost is insensitive to distance. An alternative approach, the Xerox Telecommunications Network (XTEN), employs an MDS (radio) system for local distribution. The XTEN system's distribution cost is basically independent of distance, although reception is limited to points within about forty miles of the transmitter.

The presence of the three technical alternatives poses questions about how local distribution should be accomplished. Demographic characteristics of the region served will usually determine which system has the least cost. However, the best means of local distribution could be a combination of the competing technical arrangements.

Cost Characteristics for an Example Service

For the purposes of this discussion, an example service is taken from a teleconferencing study.* The service provides four channels for one-way video and two-way audio communications. The study, which reached the now familiar conclusion that satellite systems are often the most cost-effective way to provide long distance communications, provides cost estimates for earth stations, cable distribution, and an MDS-type system. Cost equations extracted from this report are used (with simplification) in this paper to provide order of magnitude estimates. The cost structure for a region with n users is:

earth station with cable access (C)

$$c = c_1 + c_2 rn$$

rooftop earth stations (ES)

$$c = c_3 n$$

earth station with MDS system (MDS)

$$c = c_1 + c_4 + c_5 n$$

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* Teleconferencing: Cost Optimization for Satellite and Ground Systems for Continuing Professional Education and Medical Services, D. Dunn, B. Lusignan, E. Parker, Stanford University, May 1972.

where:

c_1 = cost of earth station equipped for redistribution (11,500)

c_2 = cost per mile per user for cable distribution (6,000)

c_3 = rooftop earth station cost (9,200)

c_4 = cost of MDS transmitter (86,000)

c_5 = cost of user MDS receiver (8,600)

r = average mileage for cable distribution per user.

Figures in parentheses are approximate dollar costs for installed equipment and maintenance. Note that different types of systems may have different space segment designs for minimum cost operation.

C vs ES vs MDS

The minimum cost arrangements for regions described by the variables r and n are now examined. If only one technical arrangement can be used for a region, the transitions occur at:

ES-MDS tradeoff

$$n = \frac{c_1 + c_4}{c_3 - c_5} = 162.5 \text{ (receivers)}$$

C-MDS tradeoff

$$r = \frac{c_5}{c_2} + \frac{c_4}{c_2}\frac{1}{n} = 1.4\bar{3} + \frac{14.\bar{3}}{n} \text{ (miles)}$$

C-ES tradeoff

$$r = \frac{c_3}{c_2} - \frac{c_1}{c_2}\frac{1}{n} = 1.5\bar{3} - \frac{1.91\bar{6}}{n} \text{ (miles)}$$

The boundaries of these areas are plotted in Exhibits 1-A, B, C. Exhibit 1-D displays the composite of these boundaries. The C-MDS, C-ES, and ES-MDS boundaries intersect at a common point.

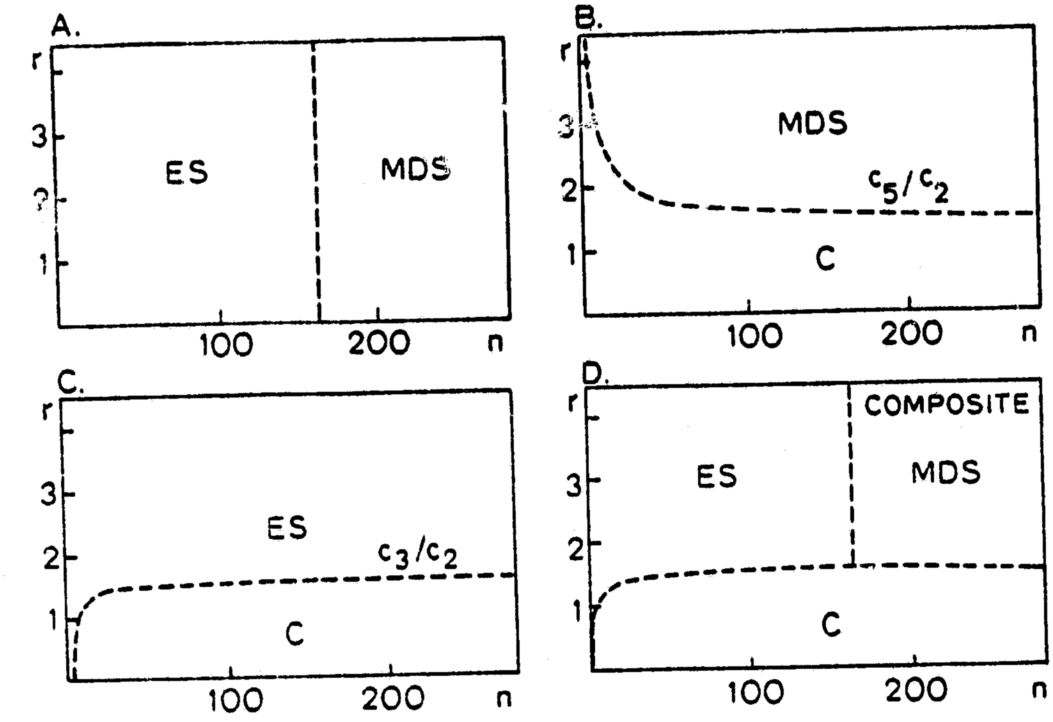
A.
r
3
2
1
ES
MDS
100
200
n
B.
r
3
2
1
MDS
c_5/c_2
C
100
200
n
C.
r
3
2
1
ES
c_3/c_2
C
100
200
n
D.
r
3
2
1
COMPOSITE
ES
MDS
C
100
200
n

Exhibit 1

Using the above cost estimates, this intersection point is at r = 1.522 and n = 162.5.

The conclusion in this case is fairly straightforward. If the demand is highly concentrated, a central earth station accessed by cable is the lowest cost alternative, regardless of the number of users in the region. If the demand is low density (geographically dispersed), then either an MDS system or rooftop earth stations dominate in terms of cost. The choice between these latter two depends only on the number of users, provided users are not so widely dispersed as to be outside the range of the MDS transmitter. Higher demand favors the MDS system, since the incremental cost of an MDS receiver is slightly less than the cost of an individual earth station (an MDS distribution system has a fixed cost as well). However, if earth station costs become low enough, the MDS system will not be a least cost alternative in any region.

<u>C vs C and ES</u>

It is sometimes possible, when the space segment allows compatible designs of two local distribution technologies, to assume that more than one technology will be used in the same system. For example, consider the joint use of cable and rooftop earth stations. Given the cost characteristics of these systems, it seems that distribution cost would be minimized by employing cable for the nearby users and rooftop earth stations for the more remote users.

Unfortunately, the boundary separating near and remote areas is not well defined by r and n alone. More information about the demography of the region is required. Specifically, we need to know the number of users n within a given radius r of the cable relay station. This information, which can be represented by a function of radius n(r), is sufficient for us to obtain a second function, r(n), which tells how average cable mileage changes as additional users are served.

For regions of interest, we will assume that all users can be ordered so that s(n), the <u>increment</u> in cable-miles required to serve the n th user, is non-decreasing. This is a useful concept since it enables an evaluation of the incremental cost of serving the n th user by alternative arrangements. If served by cable, the incremental cost is $c_2 s(n)$. If served by rooftop earth station, the incremental cost is c_4. This allows a division of users by the distribution technique serving them:

$$\text{Let} \quad \bar{n} = \max \ \{n \mid s(n) \leq c_3/c_2\}$$

then use:

C for users $1, 2, \ldots \bar{n}$

ES for users $\bar{n}+1, \bar{n}+2, \ldots n$

Note that if s(n) is not non-decreasing, a more complicated analysis is required. Furthermore, this analysis could indicate that a second central earth station accessed by cable is required to minimize distribution cost--a result that is precluded when s(n) is non-decreasing.

It can be shown that s(n) and r(n) are related:

$$s(n) = r(n) + nr'(n)^*$$

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* The total number of cable-miles is nr(n), the number of users multiplied by their average distance from the transmitter. The increment in cable-miles s(n) is just the rate of change with respect to n of total cable-miles--the derivative of s(n) with respect to n.

This relation can be used to plot an appropriate boundary for "C only" and "C and MDS" in our r - n space diagrams for various assumed "demographies" s(n). For example, suppose that regions of interest have users distributed such that s(n) is linear:

$$s(n) = an \qquad \text{for some constant } a,$$

so that $r(n) = \frac{an}{2}$ and $s(n) = 2r(n)$.

s(n) reaches the criterion c_3/c_2 at $\bar{r} = \frac{c_3}{2c_2}$ and $\bar{n} = \frac{c_3}{ac_2}$.

Note that for this special case, $\bar{r}$ does not depend on n. This example is depicted in Exhibit 2-A. As shown, for <u>any</u> linear demography, there is a threshold value above which both cable and rooftop earth stations are used jointly. This threshold is one-half the value of the threshold (in the limit) in Exhibit 1-C.

To show that the boundary is not always flat, consider a logarithmic demography defined by:

$$s(n) = a(1 + \log n) \text{ for some constant } a$$

so that $r(n) = a \log n$.

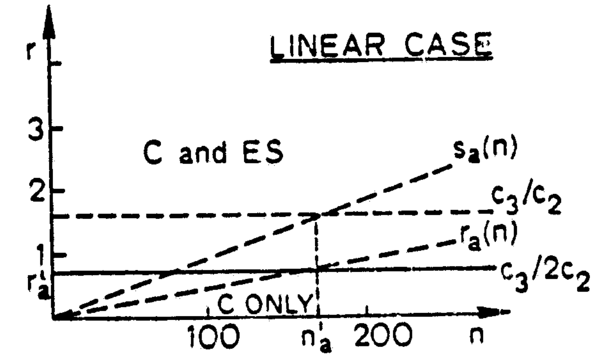
s(n) reaches the criterion c_3/c_2 at $\bar{n} = e^{1 + \frac{c_3}{ac_2}}$ and $\bar{r} = \frac{c_3}{c_2} - a$.

The resulting boundary is $\log n = \frac{rc_2}{c_3 - rc_2}$ or $n = \exp\left[\frac{rc_2}{c_3 - rc_2}\right]$.

This example is depicted in Exhibit 2-B.

It is important in the examples above to note that the boundary of the areas "C only" and "C and ES" is not invariant to the demographic "class" of the region. Even in the limit for a

A.


LINEAR CASE
r
3
2
1
r'a
C and ES
sa(n)
c3/c2
ra(n)
c3/2c2
C ONLY
100
n'a
200
n

B.

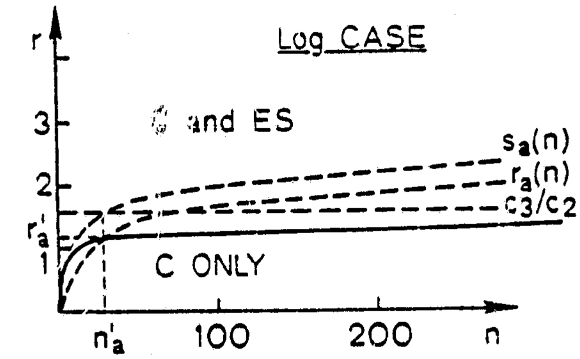

Log CASE
r
3
2
r'a
1
and ES
sa(n)
ra(n)
c3/c2
C ONLY
n'a
100
200
n

Exhibit 2

large number of users, the threshold for introduction of user earth stations depends on the type of demography assumed. For most regions of interest, the boundary is expected to be fairly flat as shown in the examples.

C vs C and MDS

Now consider the joint use of cable and an MDS system. This analysis proceeds parallel to the above analysis, except that it is slightly complicated by the presence of a fixed cost for the MDS transmitter. Otherwise, the MDS system has cost characteristics similar to rooftop earth stations. In the previous case, the behavior of s(n) after it reaches the cost criterion was irrelevant as long as it was non-decreasing; in this case, it matters.

If the systems are used jointly, cable access will be employed for nearby users and MDS receivers for remote users. The users may be divided by the criterion:

$$\text{let } n^* = \max \{n \mid s(n) \leq c_5/c_2\}$$

then use

$$\begin{array}{ll} \text{C for users} & 1, 2, \ldots n^* \\ \text{MDS for users} & n^* + 1, n^* + 2, \ldots n\ . \end{array}$$

The system will be used jointly only if:

$$\text{Cost (C only)} > \text{Cost (C and MDS)}$$

or

$$c_1 + c_2 rn > c_1 + c_2 r(n^*)n^* + c_4 + c_5(n-n^*)$$

or

$$n > \frac{c_4 + (c_2 r(n^*) - c_5)n^*}{c_2 r - c_5}$$

Consider again the linear demography $s(n) = an$ and $r(n) = \frac{an}{2}$. Transition occurs at $n^* = \frac{nc_5}{2rc_2}$ $r^* = \frac{c_5}{2c_2}$. The condition on n requires:

$$c_1 + c_2rn > c_1 + c_2 \frac{c_5}{2c_2} \frac{n}{2r} \frac{c_5}{c_2} + c_4 + c_5(n - \frac{nc_5}{2rc_2})$$

or

$$n > \frac{\frac{c_4}{c_2} r}{(r - \frac{c_5}{2c_2})^2} \quad \left[\text{for } r > \frac{c_5}{2c_2}\right]$$

Exhibit 3-A displays the boundary for the linear demography. Note that this curve is always below the curve in Exhibit 1-B, which assumed that the systems could not be used jointly.

<u>C vs C and ES vs C and MDS</u>

Now let's consider the case where cable is used and either MDS or user earth stations can be used in addition. The linear demography $s(n) = an$, $r(n) = \frac{an}{2}$ is assumed again. To determine the boundary, note that:

$$\text{Cost (C and ES)} > \text{Cost (C and MDS)}$$

$$\Longrightarrow c_1 + c_2r(\bar{n})\bar{n} + c_3(n-\bar{n}) > c_1 + c_2r(n^*)n^* + c_4 + c_5(n-n^*)$$

$$\Longrightarrow c_2 \frac{c_3}{2c_2} \frac{nc_3}{2rc_2} + c_3(n-\frac{nc_3}{2rc_2}) > c_4 + c_2 \frac{c_5}{2c_2} \frac{nc_5}{2rc_2} + c_5(n-\frac{nc_5}{2rc_2})$$

$$\Longrightarrow n > \frac{4rc_2c_4}{c_5^2 - c_3^2 + 4rc_2(c_3-c_5)}$$

In the limit on r, $n = \frac{c_4}{c_3-c_5} = 143$

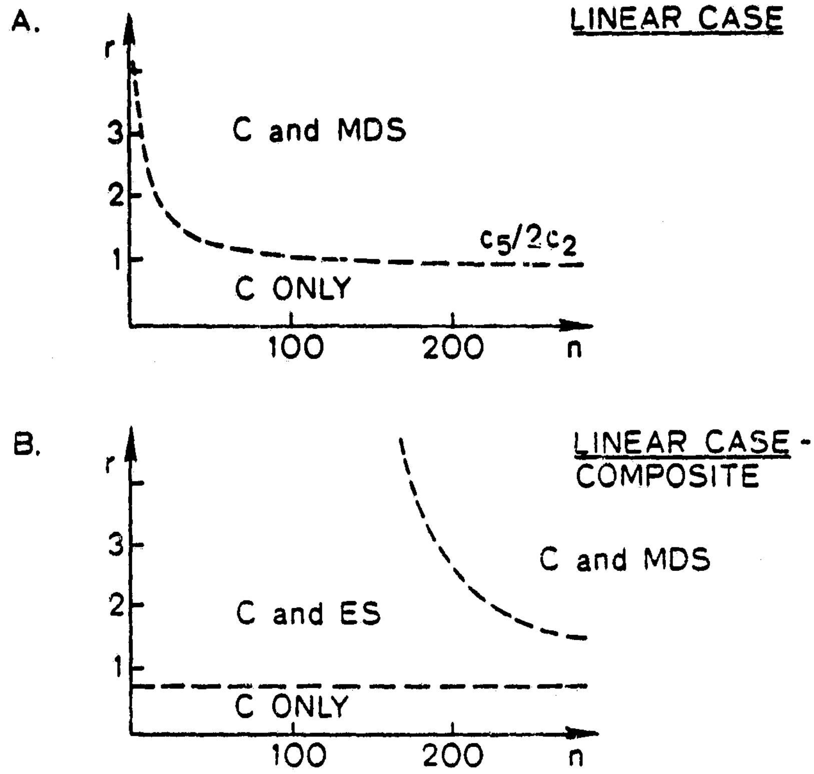

A.
LINEAR CASE
r
3
2
1
C and MDS
$c_5/2c_2$
C ONLY
100
200
n
B.
LINEAR CASE - COMPOSITE
r
3
2
1
C and MDS
C and ES
C ONLY
100
200
n

Exhibit 3

Note that the fixed cost for a central earth station does not enter in the boundary relation since both systems require it. This result is depicted in Exhibit 3-B, and represents the composite boundaries for the linear demography. Compare this figure to Exhibit 1-D, where it was assumed that only one system could be used in a region.

Remarks

In this paper, a technique has been described that can be used to determine the demographic characteristics of regions which favor different technical arrangements for local distribution of satellite traffic. The example used finds the least cost arrangement to be a central earth station with cable access for medium to high density areas of a region, combined with rooftop earth stations or MDS for more remote users in the region. The rooftop earth station--MDS tradeoff is decided principally by volume, with the latter arrangement preferred for high volumes. More analysis is required to support this finding for more general demographies.