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CURRENT PROBLEMS IN RESEARCH

Economic Potential of Communication Satellites

Satellites promise quantum jumps in overseas capacity at low cost if commercial traffic jumps too.

William Meckling

Man's first erratic sorties into space have afforded him an irresistible opportunity to indulge his fancy. The fantasy life he has conjured up encompasses both the technological possibilities and the potential benefits of space exploitation. In technological matters, "The difficult we can do now; the impossible will take a little longer," is accepted as a fact of life. Manned space platforms, moon bases, interplanetary travel, and the like are straightforward engineering problems—applications of known technology. On the social side the guiding principle is: "Benefits are directly proportional to romantic appeal." In brief, wishful thinking plays a leading role in the space drama.

A realistic appraisal, however, suggests that many a moon will set ere man establishes an encampment there and that the resources consumed in the effort will be prodigious. What is of greater importance, many more—perhaps an infinite number—will set before the investment is recovered. The same can be said for many of the other dramatic space endeavors. It will be a long time before they are realized, they will be costly, and it will be an even longer time before there is any significant payoff, if there ever is.

Amidst all this fantasy, however, there are one or two satellite applications that show definite promise of being near term. One of these is the use of satellites as communication relays. In purely physical terms, the advantage of communication satellites is the opportunity they offer for line-of-sight transmission over long distances. Because radio transmission in the atmosphere at the higher frequencies is limited to line of sight, microwave communication links at the surface of the earth must be fairly short—for example, 30 miles. For normal overland applications this requirement is not a serious disadvantage. Indeed, such links now provide at very low cost a substantial portion of our long-distance communication capacity. For transoceanic communications, however, microwave stations every 30 miles or so are impractical; and it is here that satellites come into the picture, for they enable us to have microwave links thousands of miles long.

Physical Characteristics of Communication Satellites

Basically, the idea of communication satellites is very simple. The satellite receives a signal radiated from earth and either reflects it or repeats it, for pickup by another ground station. Reflecting satellites are called passive; the Echo I balloon sponsored by the National Aeronautics and Space Administration is an example. Satellites that receive and retransmit signals are called active. Active satellites can be either immediate or delayed repeaters. Delayed repeaters receive at one time (and place) and relay the signal at a later time (and different place). The Army Signal Corps Courier satellite is an example. Immediate repeaters receive and transmit simultaneously and are called "real-time" repeaters. The Advent program of the Department of Defense is an example.

Satellites can also be classified according to orbital characteristics. The important distinction is between the so-called 24-hour equatorial orbit and all lower orbits. If a satellite is placed in orbit at an altitude of roughly 22,300 miles, its velocity will be such that it traverses a complete orbit every 24 hours. If the orbit also lies directly over the equator, the satellite will remain stationary over a specific point on earth. Satellites in lower orbits will be continuously moving with respect to points on the earth.

Satellites also differ in the extent to which their position and attitude may be controlled. At one extreme, the motion of the satellite and its orientation may be left entirely to the vicissitudes of orbital injection forces plus whatever natural forces are at work. At the other extreme, very sophisticated control equipment may be installed to control position and orientation precisely.

Obviously, a wide variety of communication-satellite systems is possible—passive, active, low-orbit, 24-hour-equatorial-orbit, real-time, delayed-time, attitude-controlled, position-controlled, and so on. Within each of these categories, of course, the number of variations in system design is virtually unlimited. There are variations in size, shape, and mount of antenna, in type of tubes, in orbital inclination, in number of satellites, in satellite weight and

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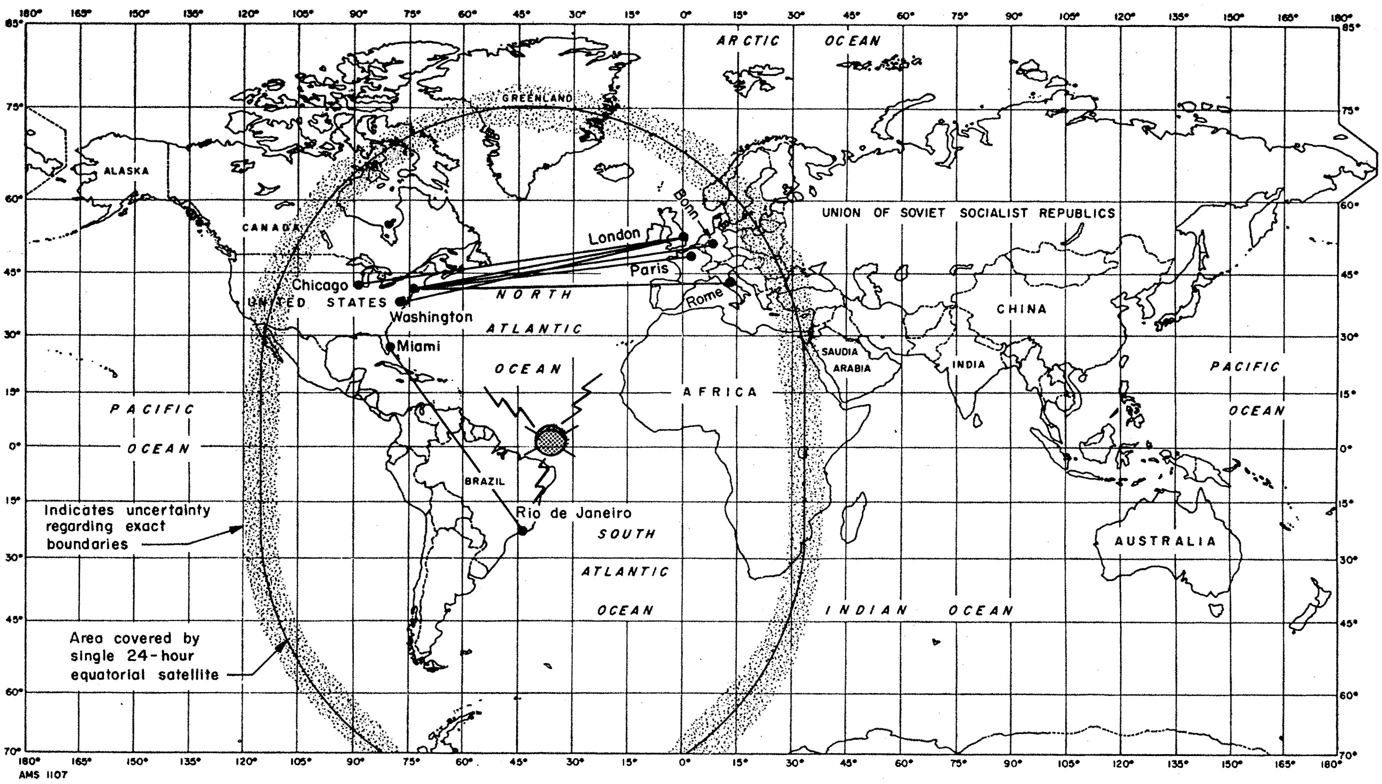

Fig. 1. Twenty-four-hour system links.

size, and so on. The various systems have different operational characteristics and pose different development problems.

Because of its great altitude, a single 24-hour satellite is simultaneously visible from widely separated points on the earth's surface (see Fig. 1), hence it could provide communication services over a large area. Three 24-hour equatorial satellites could provide continuous global coverage except for the polar regions. Such extensive coverage, however, also imposes penalties. For one thing, the energy required to place a given payload in orbit increases with altitude. For another thing, the 24-hour satellite will need position- and attitude-control systems to overcome natural forces tending to pull it out of orbit, as well as to offset any initial orbital placement errors. Position and attitude control adds to complexity and reduces reliability. The 24-hour equatorial system, because of its complexity and the requirement for large boosters, will probably take longer to develop than some of the other systems.

With lower-altitude systems the receiving and transmitting antennas at the ground terminals must sweep from horizon to horizon. They must focus on the satellites as they become visible over one horizon and follow them until they disappear over the other. As each satellite disappears, a new one, visible to both ground stations, takes its place. Because the area of simultaneous visibility is reduced at the lower altitudes, more satellites are required to provide continuous (or nearly continuous) service between any pair of ground terminals. In low-altitude systems the problems of development and reliability can be eased by dispensing with the attitude- and position-control systems, but this too increases the number of satellites required. Without position control, the satellites are randomly spaced, hence more satellites are required to insure that at least one is, at nearly all times, visible to each pair of ground stations.

All of the systems under serious consideration for commercial communications require very large receiving antennas and very sensitive receivers. The former must in effect be radio telescopes of the sort used by astronomers. The reason for this requirement is the low signal strength in the link from satellite to ground. With passive systems the reflected signal is quite weak at the distances involved, and even with active systems the power available in the satellite will be relatively small, at least in the near future. Because of this, it will be many years before satellites can be used for general broadcasting. Relay of television and radio programs from one terminal to another via satellite will be possible, but rebroadcast will be necessary for local audiences.

Uncertainties

The problem of evaluating the economic prospects for communication satellites is in principle the same as the problem of evaluating any other long-term production process. The development, production, and operation of a satellite system will require a stream of future expenditures and will provide a stream of receipts. Of course, a large number of alternative satellite systems might be developed. Moreover, each of them could be developed on a variety of schedules. Also, there are alternatives to communication satellites—for example, submarine cables—to be considered. If we knew the relevant expenditures and receipts profiles for each of the alternatives, we could determine the optimum program for providing future communication services.

Needless to say, in the real world we are going to have to settle for a lot less than this ideal. We are not going to forecast with much accuracy either the stream of costs or the stream of

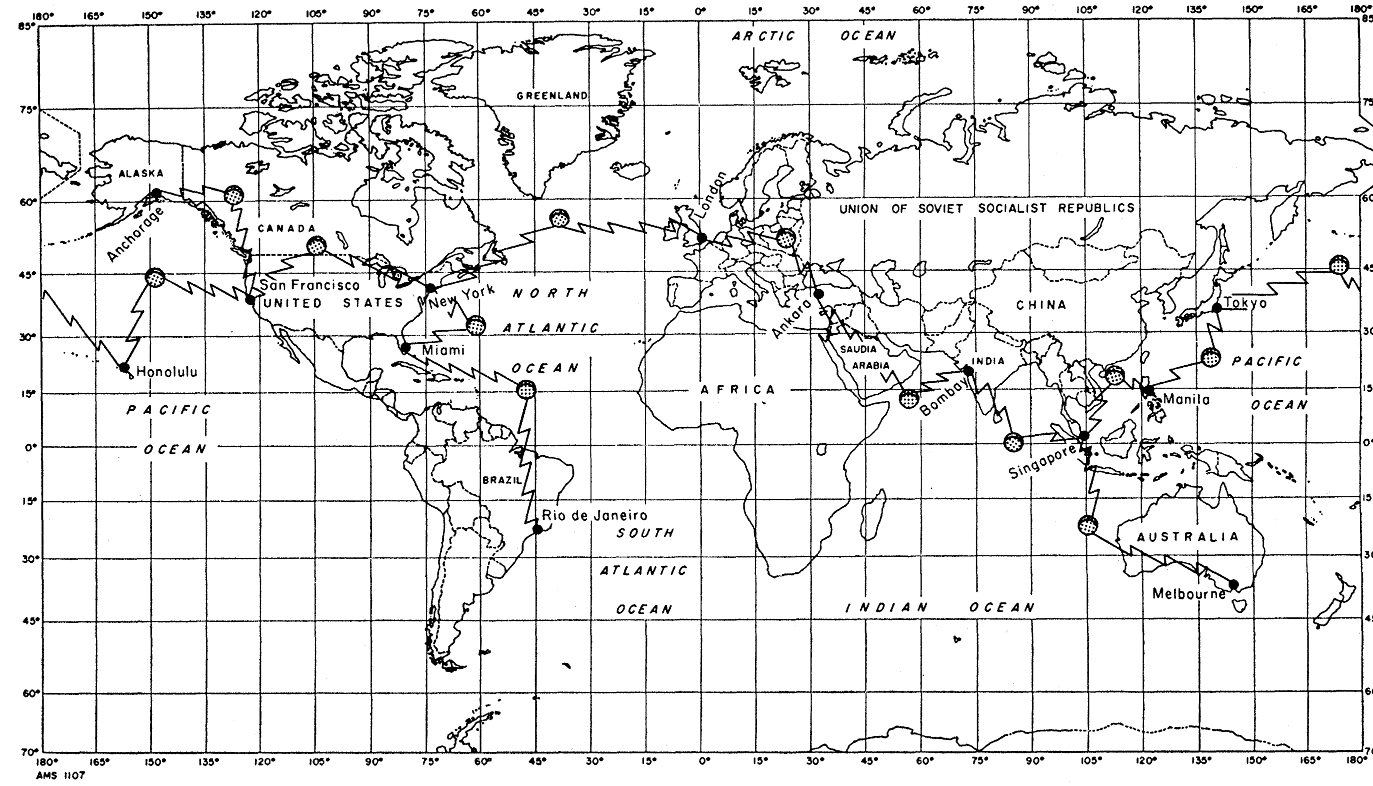

Fig. 2. Low-altitude-system links.

revenues for any system. The cost of various kinds of satellite systems depends on a host of technological questions that won't be answered even approximately until development has been carried much further than at present. What will be the useful lifetimes of various satellites? What will happen to launching costs? What will the probabilities of launch success be? How many usable channels can we really get out of given equipment? And so on.

Uncertainty about receipts is, if anything, greater than uncertainty about costs. Forecasting the demand for telephone and telegraph services 10 or 15 years in the future is difficult enough, let alone forecasting such things as demand for international television or data processing. In brief, until more evidence is available, conclusions must be regarded as tentative.

Costs of Communication Satellites

From the extensive array of candidates, two rather promising systems have been selected for analysis here. One is a low-altitude system; the other is a 24-hour equatorial system. Both are real-time active communication systems.

In the low-altitude system, there would be a maximum of 120 very lightweight active satellites in orbit at any given time. The satellites would be multiple-launched—that is, a number of them (say 40) would be placed in orbit with a single firing. They would not be position-controlled but would be dispersed around the earth in belts, with random spacing within each belt. It is estimated that one of these repeaters could provide either 600 *one*-way telephone voice channels or one television channel between a pair of stations. *Two*-way voice communication is achieved by using two different satellites visible simultaneously from two ground stations. Because of the large number of satellites in orbit, at least two satellites would be simultaneously visible from any pair of ground stations more than 99 percent of the time.

The ground network postulated consists of 13 stations encircling the world, as shown in Fig. 2. Since 600 pairs of two-way voice channels are provided between any pair of stations, the total capacity is 7800 station-to-station channels.

The 24-hour system considered here employs a single large satellite in a 24-hour equatorial orbit over the Atlantic. It is estimated that such a satellite could provide 4800 two-way voice channels. Part of the capacity (600 one-way channels) could be used for television, if desired. Service between seven pairs of stations is postulated—New York and London, New York and Bonn, New York and Paris, New York and Rome, Washington and London, Chicago and London, and Miami and Rio de Janeiro—as shown in Fig. 1. For global coverage three such satellites would be required, but the annual cost per voice channel (which is used here as a basis of comparison) would not be materially affected.

The two satellite systems present different problems from the point of view of service interruption. Because of the random spacing of satellites in the low-altitude system, two satellites would not always be visible from each pair of ground stations. This means that for any given link, interruptions of a few minutes' duration would be a daily occurrence. On the other hand, satellite failures would only gradually degrade the capability of the low-altitude system. As failures occurred, the interruptions would gradually grow more frequent and of longer duration.

With the 24-hour system, uninterrupted service would be provided around the clock except when a failure occurred. When that happened, however, it might be days or even weeks before service could be restored because of the time required to successfully launch a replacement. Such interruptions would not be tolerable from an operating standpoint, and we have therefore assumed that a spare satellite will be kept in orbit with the 24-hour system. This is an important factor in the cost.

For both systems a 15-year life is assumed for ground equipment. Development costs, launch costs, and terminal operating costs throughout the life of the systems are all included.

Different systems entail different patterns of expenditure with time. Submarine cables require a large initial outlay relative to annual operating costs, while for satellite systems the annual charges for launching and operation represent a larger proportion of the total cost. In order to make valid comparisons between systems, costs must be adjusted to take account of different time profiles of expenditures. What this means is simply that interest costs must be correctly incorporated in the analysis. The interest rate used in this study is 8 percent.

Cost based on full utilization. The cost data are summarized in Figs. 3 and 4. The unit of measure is cost per (two-way) station-to-station voice channel per year.

In an attempt to take account of some of the uncertainties cost curves are shown for a variety of assumptions. The parameters which are varied are (i) mean time to failure (MTF), (ii) probability of launch success, and (iii) load factor. These are not the only important parameters, but only a limited number of variations can be presented here.

Figures 3 and 4 also show costs for submarine telephone cables and for the TD-2 microwave relay system. The TD-2 is an important type of overland microwave system used by the American Telephone and Telegraph Company for long-line communication channels. The microwave costs are system-wide averages based on the company's experience in the United States. As previously mentioned, microwave links are not practical for transoceanic communications; they are included here to indicate the competition satellites will face in *overland* transmission. Submarine telephone cables are the chief competitor of communication satellites in transoceanic communications. Such cables are themselves a new development. The first transatlantic telephone (not telegraph) cable was placed in service in 1956. The cable costs shown in Fig. 3 are for a new type of cable which the American Telephone and Telegraph Company plans to lay in 1963; they are substantially lower than costs for existing cables. Unlike costs for communication satellites, costs per channel for cable and microwave systems depend on the length of the link, hence they are shown as a function of circuit length.

Figure 3 shows estimated annual costs per (two-way) voice channel for the two systems, based on full utilization. The term "cost per voice channel," as used here and in subsequent discussion, is synonymous with "cost per unit of output," as that term is usually understood. For communication systems, output is measured in terms of voice channels *actually used*. Thus, to compute cost per unit of output, some assumption must be made about utilization. In computing the cost per channel (that is, cost per unit of output) in Fig. 3, the number of channels used (the output) was taken to be equal to the capacity of the system. Looked at from a slightly different viewpoint, the costs shown are the level annual prices that would have to be charged per voice channel in order to recover all costs, if all channels are sold every year. Thus, for the low-altitude system, when the mean time to failure of the satellites in orbit is 2 years and the probability of launch success is .75, a price of about $8500 per year per channel would just cover all costs, if all channels were sold at that price each year. For the 24-hour system, when the mean time to failure is 1 year and the probability of launch success is .75, a price of about $10,000 per year per channel would also cover all costs, if all channels were sold at that price each year. By comparison, for the new cables, the annual cost of a 3000-mile transoceanic link would be about $27,000 per voice channel. To put these figures in perspective—the telegraph companies pay $240,000 per year for one voice channel in the existing submarine cable. This bears out a point mentioned earlier: costs with the new cables will be substantially lower than costs with the present cables. Moreover, it appears that substantial reductions in toll charges should be possible—a fact that is of some interest in later discussion.

The ultimate potential of communication satellites is clear from these curves. Even with very pessimistic assumptions for mean times to failure, probabilities of launch success, and launch costs, satellite costs are lower than cable costs for any but very short links. On the other hand, only with much more optimistic assumptions than any we have made could we conclude that satellites will be competitive with microwave relays in conventional overland applications. There are some land areas, of course, where terrain factors might make a satellite system competitive with microwave relays, and some overland links—for example, from San Francisco to New York—might be available at very low marginal cost, given a global satellite communication system.

Figure 3 also seems to indicate that costs per channel for the low-altitude system are below those for the 24-hour satellite system for roughly comparable assumptions. (We assume shorter mean times to failure for the 24-hour system because of its greater complexity.) However, it would be rash indeed to conclude in favor of one or the other on this basis. The range of uncertainties is much too large for us to decide this question now.

Cost based on geometric increase in use. By present standards, satellites represent very-large-capacity international communication systems. In mid-1960 there were only 105 telephone voice channels between the United States and Europe and only 240 additional channels between the United States and other overseas points—345 in all. Even by domestic standards the capacity of communication satellites is impressive. At that same date, for example, there were some 850 channels between Los Angeles and New York and 2600 between New York and Chicago (*1*).

Thus a world-wide, low-altitude system with 7800 voice channels would provide about 20 times the number of transoceanic channels presently routed to the United States, and a single 24-hour transatlantic satellite with 4800 voice channels would provide about 45 times as many channels between the United States and Europe as are presently available. To appreciate the magnitude of these figures, one should remember that international telephone traffic to and from the United States in the last 10 years has increased by only a factor of 3.

For our purposes, the important point is that costs per unit of output, computed on the basis of full utilization, appear to be biased on the low side. One very convenient way to take

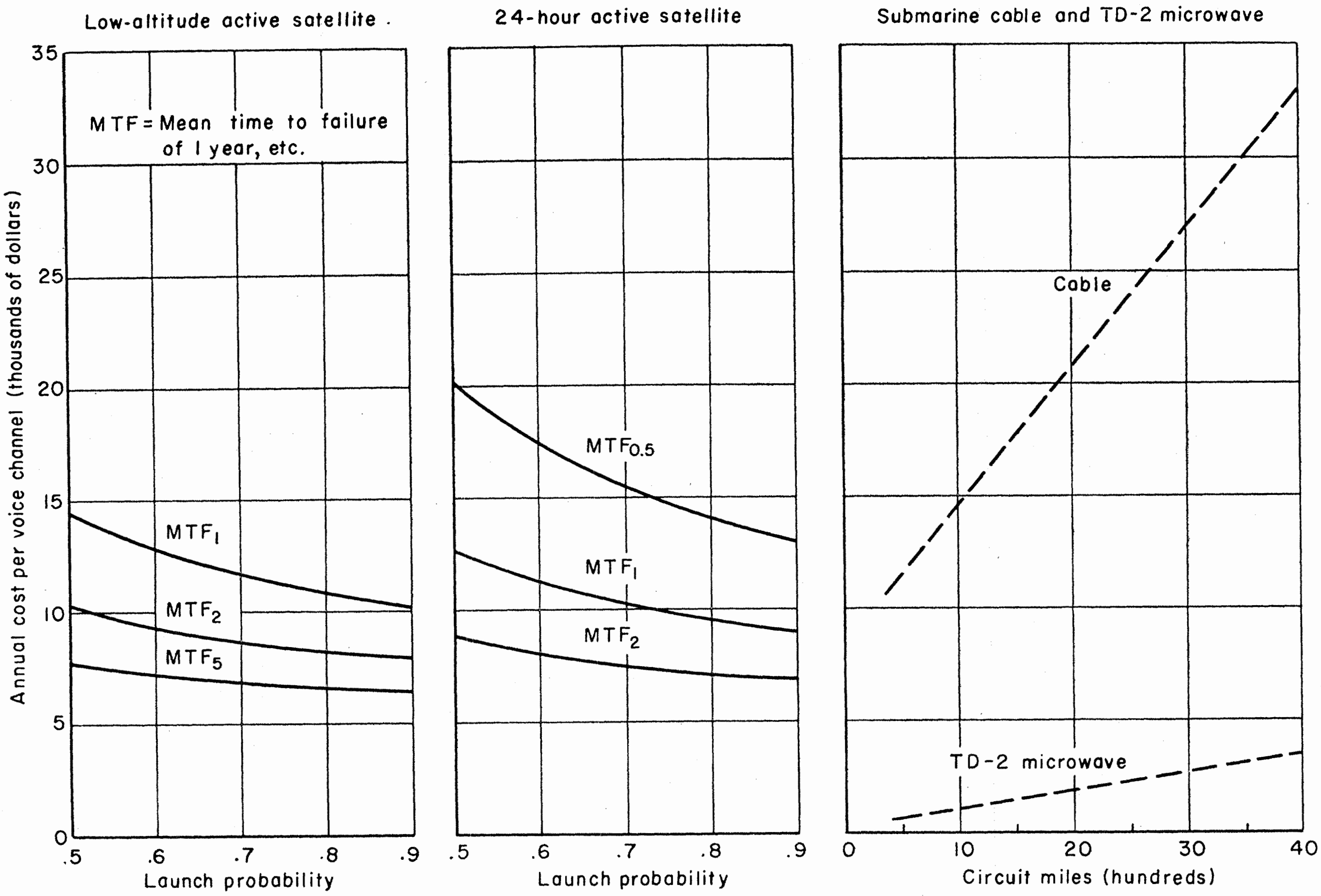

Fig. 3. Annual cost per voice channel on the basis of full utilization. MTF_1, average effective life of 1 year; MTF_2, of 2 years; and so on.

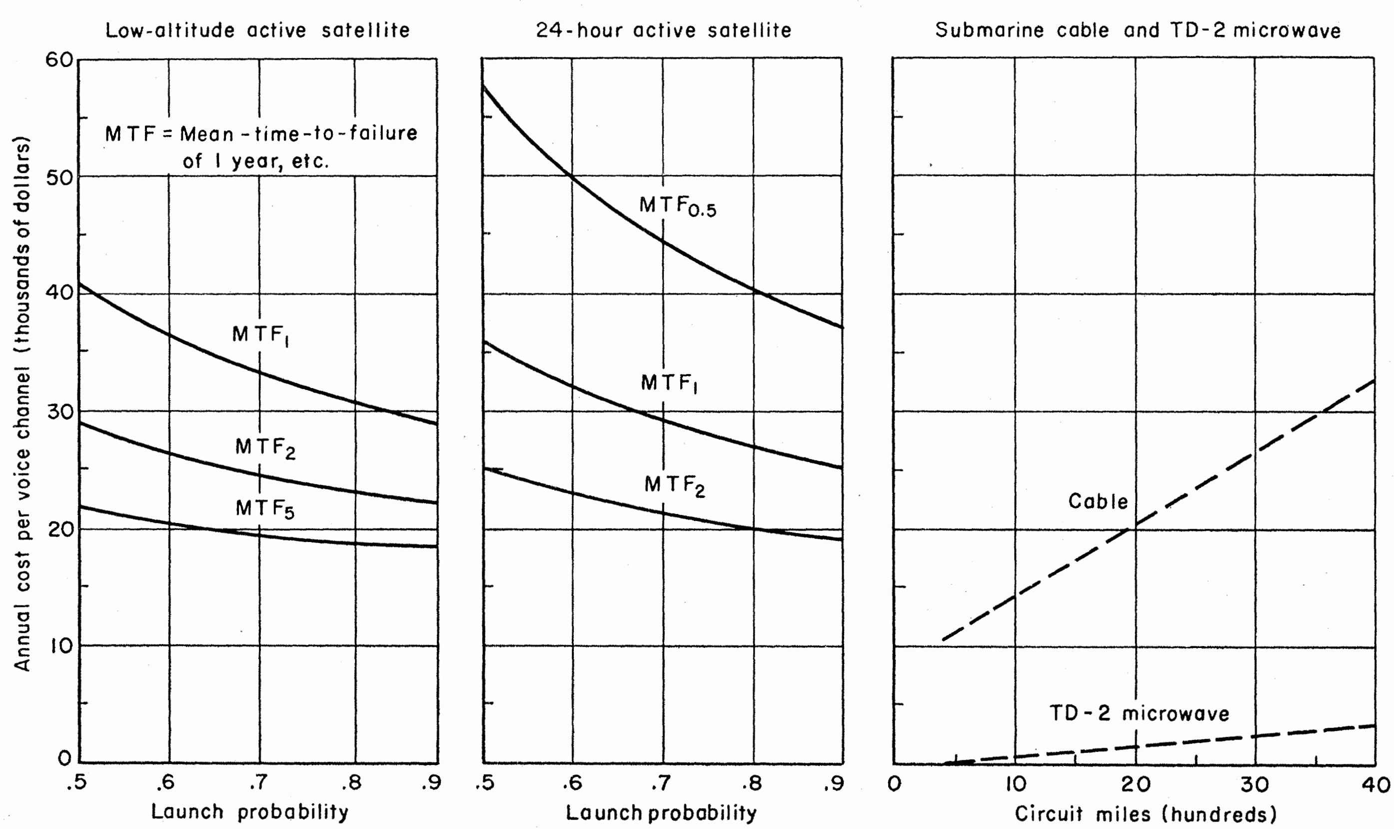

Fig. 4. Annual cost per voice channel on the basis of geometric increase in use.

account of this possibility is to use load-building factors in computing the cost per channel. This has been done in Fig. 4. Annual costs per channel, as shown there, are based on the assumption that satellite use builds up geometrically over the life of the system. In line with our earlier discussion, this is equivalent to assuming that output increases geometrically. For the low-altitude system it is assumed that 1000 channels are sold in the first year of operation and that thereafter sales increase at a rate of 15 percent per year, compounded annually, reaching capacity (7800 channels) in the 15th (and last) year. For the 24-hour system, it is assumed that 600 channels are sold in the first year and that there is the same 15-percent increase, compounded annually. The possibility of realizing a 15-percent annual increase is analyzed in the next section.

The effect of these more conservative growth assumptions is to multiply costs per voice channel—that is, per unit of output—by a factor of almost 3. For a 2-year mean time to failure and a probability of launch success of .75, the annual cost per channel for the low-altitude system is $24,000, as compared with $8500 in Fig. 3—only slightly less than the $27,000 cost per voice channel of a 3000-mile cable link. For the 24-hour system, with a mean time to failure of 1 year and a probability of launch success of .75, the cost per voice channel is about $27,500—slightly above the cost of a 3000-mile cable link.

The importance of high rates of use for communication satellites is clear. Without them, satellites promise significantly lower costs than submarine cables *only* if extreme reliability is achieved.

Demand

Communication satellite systems are in effect large-scale plants for producing communication services. As such, they appear to promise economies of large-scale operation; they promise lower unit costs than submarine cables if high output rates (or, what is the same thing, high utilization rates) can be achieved—high relative to current international telecommunication traffic. How large an increase in output the market will support depends on two factors: (i) how demand increases over time, and (ii) how sensitive utilization rates are to price reductions. Prices are particularly important. To judge by the current rate of $240,000 for a transatlantic voice channel, substantial price reductions should be possible with either the new cables or communication satellites. If consumers respond to lower prices by greatly increasing their use of international telecommunication facilities, communication satellites are very likely to be the more economical of the two alternatives.

Unfortunately, both the course of future demand and the responsiveness of the market to lower prices are very difficult factors to estimate. Economic projections 10 or 20 years into the future are always highly uncertain. In the case of communication satellites, changes in the international political environment, through their impact on international trade, travel, investment, and so on, could have a dramatic effect. New inventions that are substitutes for, or complementary to, satellites also could revolutionize demand.

Despite the uncertainties, however, an examination of the growth of international communications is useful in judging whether there is any hope for enough traffic to support a satellite system. Since overseas telephone and telegraph presently dominate the market, let us look at those first. Later we shall discuss very briefly some of the new uses that have been proposed. Although the use of satellites would not be limited to U.S.-centered traffic, this component would probably be the largest, and we center our attention upon it.

Overseas telephone and telegraph services. Since the depression of the 1930's, overseas telephone communications have grown steadily and rapidly. Figure 5 shows the annual totals for inbound and outbound overseas messages for the United States for the period 1930–59. During those 30 years the number of messages increased by a factor of 100. In the last 10 years the volume of messages roughly tripled. As is evident from the regular slope of the line, the rate of growth has been remarkably constant since 1946. If that same growth rate persists, the volume of overseas messages will reach 10 to 12 million by 1970 and around 40 million by 1980. The dotted line *B* in Fig. 5 is based on a growth rate like that of the postwar period. The dashed line *A* is based on a substantially higher growth rate, which predicts 20 million or so messages in 1970 and 100 million by 1980. *A* corresponds roughly to the assumption of a 15-percent annual increase—the assumption used in computing the costs shown in Fig. 4.

The history of toll rates is an important consideration in interpreting Fig. 5. The period of stable growth from 1946 to the present coincides with a period of stability in international telephone rates. The last change in rates to London occurred in 1945, and though rates to some other countries were lowered in 1946, there have been no changes in international rates since then. When increases in price level are taken into account, it is clear that there has been a modest decline in real rates. Thus the real price of calls to London fell about 20 percent during the 14 years from 1946 to the present. Prior to 1946, rates to London were reduced from $45 in 1929, to $30 in 1934, to $21 in 1936, and to $12 in 1945. In addition, special night rates were introduced in 1936.

The growth of telephone traffic during the 1929–45 period follows rather closely the pattern of real rate changes. From 1929 to 1934 real rates to London rose, because nominal rates were fixed while the price level was falling. During those years international telephone traffic actually declined. From 1934 on, however, real rates to London fell dramatically, so that by 1946 they were about 20 percent of what they had been in 1929. These were also the years during which telephone traffic experienced its fastest growth. In 1946 message volume was about 20 times what it had been in 1935. Thus, for the 30 years covered by our data there is a high correlation between real rate changes and the volume of telephone calls. When real rates were fairly stable (1946–59), there was a stable growth in number of calls; when real rates rose (1929–34), the number of calls declined; when real rates fell substantially (1935–45), there was a rapid growth in number of calls.

In brief, historical data on the growth of international telephone traffic indicate that (i) the demand for international telephone service has grown rather impressively over the last 30 years, and (ii) utilization rates are quite sensitive to price reductions. If both statements are true, and if they continue to hold in the future, a growth in number of telephone messages such as that represented by *A* in Fig. 5 is certainly a possibility—that is, of course, if potential reductions in toll rate are in fact realized. Furthermore, it should be noted that the increase in utilization will exceed the increase in message volume. Estimates of message volume by itself ignore one dimension of utilization—namely, the duration of calls. Not only will the number of calls increase if toll rates are reduced, but the average length of calls will increase.

In terms of both revenue generated and message volume, international telegraph traffic to and from the United States exceeds telephone traffic. For a number of reasons, however, the telegraph business is likely to play a minor role in the communication-satellite picture.

First and most important, much less communications capacity is required for telegraph transmission than for telephone. One telephone voice channel is roughly equivalent in capacity to 20 telegraph channels. Thus, telegraph is a modest consumer of the one thing a satellite system provides—large quantities of long-line capacity.

Second, with telegraph there is less opportunity for increasing utilization by reducing toll rates, because long-line transmission costs are a relatively small proportion of the total cost of a message; reductions in transmission costs will not appreciably affect the cost per message.

Third, telegraph also looks less promising from the point of view of traffic growth. The volume of telegraph messages to and from the United States is only about 25 percent greater today than it was 30 years ago, though all of that growth has occurred since the end of World War II. Certain special forms of telegraph service—private leased lines and Telex (a means of conducting conversations by telegraph)—have been growing rapidly, but these constitute a relatively small part of the total.

Finally, in many parts of the world where telegraph is important, communication-satellite channels will not be available for telegraph applications. Because of their high cost, the number of satellite ground terminals will be limited (most countries simply won't have terminals), and, where there are no terminals, telegraph traffic cannot be channeled through the satellite system.

Proposed supplemental uses. No consideration of the demand for communication satellites would be complete without a discussion of the varied assortment of supplemental uses that have been proposed—for international commercial television, data transmission, facsimile transmission, closed-circuit television, and so on. In the fields of international telephone and telegraph, we at least have a history to rely on, but there is virtually no experience to help in evaluating these proposals. What can be said is, therefore, even more tentative and less quantitative than predictions in the other two fields.

Commercial television is the use that has received most attention. The operational difficulties in international television are well known by now. Time and language differences limit the market. For much of the world, simultaneous broadcast of the daily fare would be out of the question, and even briefly delayed broadcasts, such as those used for different time zones in the United States, would not be feasible. Special events like the Olympics could be broadcast simultaneously to some areas. But even here, delayed broadcast by tape would probably be more satisfactory. For delayed broadcast the question is: What advantage would satellites offer over delivery by fast aircraft—that is, how much more would television sponsors be willing to pay for satellite transmission? Such transmission is going to be costly. Even with favorable assumptions, it appears that the annual cost of 600-voice channels in a communication satellite will be substantially larger than the cost of domestic microwave relays.

One important possibility for encouraging new uses, such as delayed television facsimile transmission, and

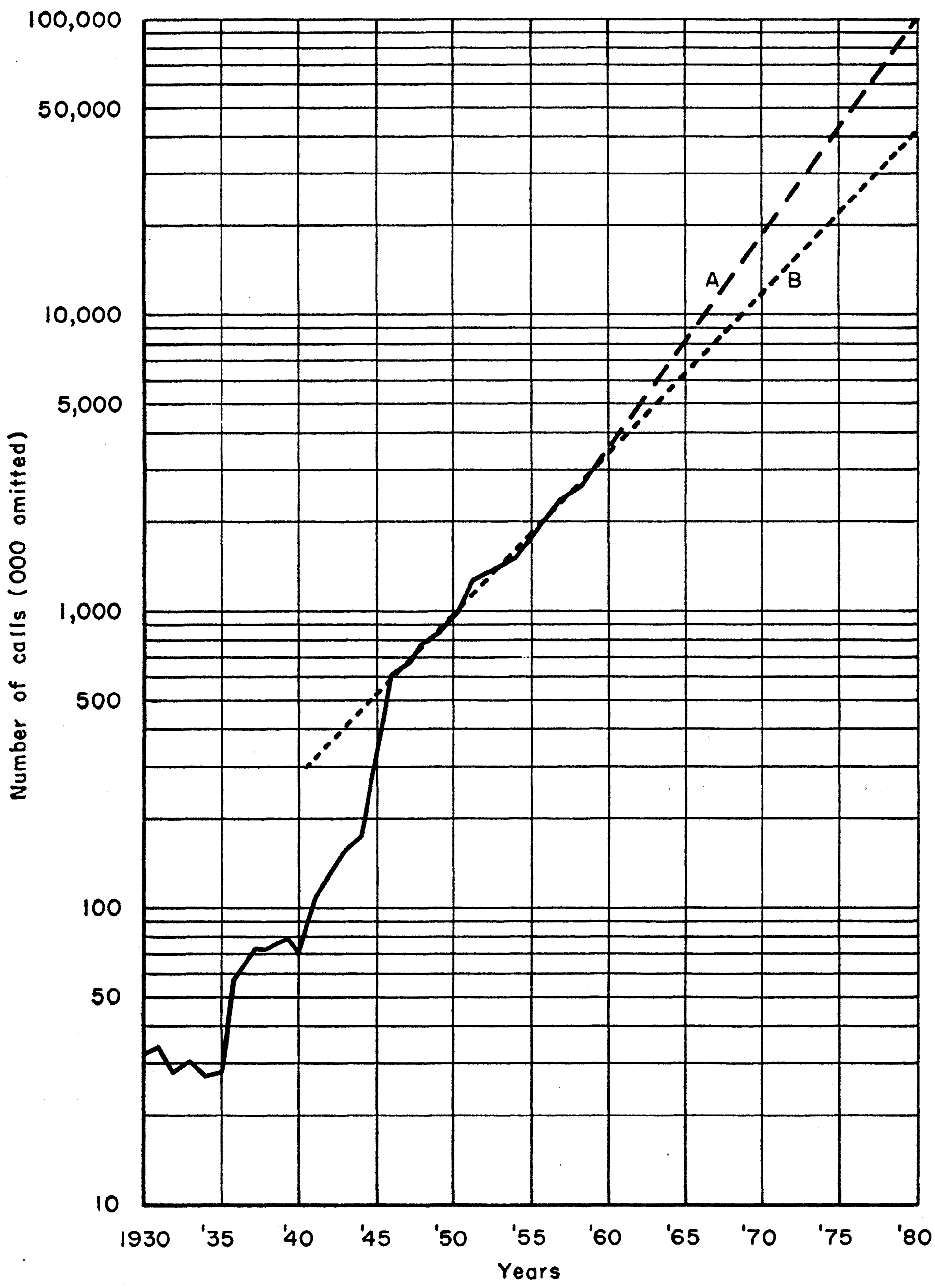

Fig. 5. Overseas telephone calls per year to and from the United States for the period 1930–59 and projections based on two growth rates (see text).

data transmission, is to inaugurate a policy of varying prices with the time of day. During "off-peak" periods, communication-satellite systems will have large "excess capacity." Once the system is in operation, the cost of using the excess capacity will be slight. Thus, it may be possible—say, during the night—to use the satellites for transmitting facsimile mail and taped television or data at very low prices. Unless some such arrangement is made, the potential demand for such uses is likely to be small.

If a low-cost method is found for bringing closed-circuit television into homes and offices, this could generate an important demand for international communication capacity, probably a much more important demand than that of commercial television. Though much more expensive than telephone, it would provide a close substitute for travel for many business and official purposes.

Thus new forms of international communications—probably some kinds that are not recognized today—will add something to the demand for capacity. Whether they will dramatically increase total demand or will have only a modest effect is hard to say.

Communication satellites promise substantial reductions in cost, as compared to the new submarine cables, if high rates of utilization can be achieved. The real question, therefore, is demand: Just how soon will demand be sufficient to support such systems? If we judge on the basis of past growth of international telephone traffic, plus possible channeling of telegraph traffic and potential new uses, that day may not be too far in the future. That does not mean it will be next year, however, or even 1965, but some time thereafter (*2*).

References and Notes

1. F. R. Kappel, "Communications in the space age," lecture delivered at the University of California, Los Angeles, 29 June 1960.

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Dilemma of Academic Biology in Europe

University customs steeped in the past make difficult the development and retention of creative scientists.

William V. Consolazio

The observations reported in this article are the result of approximately a year's stay in Europe, recently made possible by the National Science Foundation in its newly inaugurated advanced study program set up for the purpose of augmenting the skills and understanding of its career scientific staff.

The deeper I probed into this survey of the organization and the needs of European academic biology, the more I became convinced that whatever I reported would be a first approximation to a most complex and singularly important subject. In spite of extensive effort, the time I spent abroad proved much too short for the needs of the task. Several specialized biologists could have been profitably occupied at this chore, each spending as much time in each of the countries I visited as I did on my entire trip.

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I would like to begin by defining a few terms. Although I have used the term *science* throughout this article, I refer specifically to the biological sciences in the broadest sense. I have written about European science. Actually, I refer to science in Europe west of the Iron Curtain. I visited all but two countries in Western Europe. I include Israel, not only because I visited there but also because, intellectually, Israel is part of the West.

I visited as many centers of research as time and my professional interests permitted; however, I visited people rather than institutions. Before I left the United States I prepared an itinerary based on the recommendations of many American experimental biologists who know Europe and whom I hold in great respect.

It is a truism that science is international; it knows no national boundaries. It is also axiomatic that whether or not there is science in a country, or whether there is a good or a bad science, depends on the number, quality, and training of the nation's scientists, the availability of research funds, the extent of the nation's educational facilities, and the state of its research equipment and laboratories. But more than this, the nature of a nation's science depends on the intellectual and scientific traditions and attitudes of that country—I would say on the intellectual and scientific receptivity of a nation. One thing is clear: no nation has a monopoly on intelligence and on scientific potential. Bright young men and women are just as common in the more unfortunate and poverty-stricken countries as they are in the wealthier and intellectually more highly developed nations. The only difference between the haves and the have-nots with respect to scientific potential lies in the fact that in the more fortunate countries young people are better trained and utilized, and that the potential is thus more fully exploited. Despite our self-castigation, we in the United States don't waste nearly as many young people as are wasted in Central and Southern Europe.

It is well known that, of the countries I visited, science is most highly developed in the British Isles, in Israel, and in Sweden. There are pockets of scientific activity of very high quality in most of the other countries of Western Europe, but on the whole one can say that as one proceeds south, both the quality and the quantity of scientific activity decline. But let me add