Bringing advanced technology to rural America

The cost of technology adoption

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This study examines the factors that are working for and against the development of an advanced telecommunications infrastructure to serve rural areas of the USA. There is a notable difference between the costs of local network upgrades for existing rural telephone subscribers and of bringing service to new and physically remote subscribers. The latter group should be treated separately for policy purposes. The infrastructure serving the existing subscriber base could be upgraded to a digital network without necessitating large rate increases, provided there is sharing of network facilities between the energy, transportation and telecommunication sectors. The preferred medium is likely to be digital fibre.

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[1]*New York Times*, 5 November 1989.

[2]A recent discussion of these and other issues appears in Edwin B. Parker *et al*, *Rural America in the Information Age*, University Press, Lanham, MA, 1989. Some cost/benefit analysis appears in an earlier paper, Edwin B. Parker, 'Economic and social benefits of the REA telephone loan program', draft, Stanford University, 24 March 1981.

Technology adoption in communication networks occurs at a very rapid pace, but in today's competitive marketplace the significant advances are concentrated in specialized private applications and dense urban areas. Not wanting to be left behind, regulated telephone utilities actively deploy new technology in dense markets to compete with private carriers. Thus many Americans are left at a technological disadvantage in an information-oriented society, raising the spectre of 'information gaps'. Some evidence of the level of social concern regarding rural telecommunications appeared in a *New York Times* article which suggested that the rapid introduction of new digital and fibre-optic technology in private markets may lead to the formation of a 'communications elite'.[1]

While an efficient communications infrastructure is necessary for rural economic development, its financing raises a multitude of socio-political issues.[2] There are endless arguments among various interest groups regarding subsidies to promote rural development. Much of rural America is served by small independent telephone companies. Historically, financing for the modernization of rural network facilities has come from local rates and toll settlement payments received for providing network facilities to long-distance telephone companies and their toll service customers. Increased competition has added an element of uncertainty to the expected revenues derived from these sources. Meanwhile, lower toll rates have resulted in an increase in calling volume. To date this has actually resulted in an even higher net toll income for rural companies. But the days of large cross-subsidies are surely numbered. Large business customers and telephone companies want to reduce toll settlement payments to small telephone companies. The greater short-term danger to rural companies lies in the *de facto* 'de-averaging' of toll rates, at first through discount plans of unregulated carriers, whereby a call of equivalent distance would cost more

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on a low-volume rural route than would a similar call on a high-volume urban route. In this case long-distance rural calling would diminish along with toll income of the rural telephone companies. These events may not only hinder rural network modernization and service quality, but may threaten the very survival of many rural telephone companies.

While specific demand and institutional factors are potentially very important, they are beyond the scope of this study, which assumes that the current institutional environment will continue featuring common-carrier regulation of telephone utilities. To what extent certain features of the existing environment are hindering or enabling factors for an advanced rural telecommunications infrastructure will be identified. Prices and demand are assumed to remain at today's levels, although new service capabilities that advanced networks can offer will increase demand, perhaps substantially. Thus the analysis herein is considered quite conservative in that it concentrates on the cost side of the equation and does not impute substantial new revenues to the profit picture.[3]

Study results

The results of this study indicate that fibre optics is the technology of choice for all shared network facilities where terrain permits. For dedicated subscriber loop plant there are several viable alternatives: coaxial cable, copper wire and digital radio service, for example. Microwave is also preferred for some applications of shared plant. In the future, however, digital fibre optics will dominate. Due to significant variations in local demographics and topography, the analysis and conclusions may not apply in many specific rural areas although they are relevant for broad public policy considerations.

The cost of advanced rural communication network infrastructures is substantial; however, it may be possible to finance its construction given the existing customer base, without significant increases in subscriber rates. Assuming a construction interval of 10–20 years – a normal time span for turning over telephone plant – one estimate of the cost of digital service is about $1000 per subscriber.[4] This would endow rural subscribers with digital communication capability comparable to narrowband ISDN service. While this may suffice for residential subscribers using home computers or other devices, such narrowband service capability may not meet the communication requirements of business customers. As subscriber needs develop, broadband services using fibre-optic technology or other suitable media may become necessary.

Though achieving broadband communication capability is a costly proposition, at over $5000 per rural subscriber, it could still be managed over a construction interval of 10–20 years.[5] Broadband communication facilities would allow consumers to enjoy high-quality service, including entertainment video, and multimedia applications where more than one communication activity may occur simultaneously. For example, with broadband telephony one may access an on-line database while viewing a movie, reading or listening to electronic news. The cost of such capability is high because it requires new alternatives for subscriber loop plant to replace traditional twisted-pair copper telephone lines.

Where possible, existing coaxial cable television loops could be interconnected to a fibre backbone of shared network facilities to provide broadband capability. Elsewhere, fibre-to-the-home (or 'near' the home) is required. Satellite and microwave radio will not be the best

[3]For a discussion of new services and public benefits see Mary Gardiner Jones, *The Consumer Interest in Telecommunications Infrastructure Modernization*, Consumer Interest Research Institute, Washington, DC, January 1990; also see the discussion and references listed in Bruce L. Egan, *The Case for Residential Broadband Networks*, Research Working Paper 456, Columbia Institute for Tele-Information, New York, NY, August 1991.

[4]This estimate is a broad average and depends heavily on embedded subscriber loop plant characteristics. For example, where digital switching is already available and digital loop carrier or remote switching exists, the average cost of a digital upgrade is about half this amount, or $500. In older plant (about half of the embedded base) the per-subscriber costs are much higher (about $2500) due to digital switch replacement and rehabilitation of 'non-filled' cable plant which generally will not support digital service. For a description of rural telephone plant characteristics, see Gerald S. Schrage, Chief, Systems Engineering Branch, Rural Electrification Administration, 'Rural subscriber loop performance', *TE&M*, 15 January 1988. Many of the cost estimates in this article are based on formal and informal private correspondence between the author and various experts. Hastad Engineering Company in Minneapolis performs network upgrades for small telephone companies and provided some useful cost estimates.

[5]There are several recent books about residential broadband networks. For a survey and discussion of the cost of residential broadband networks, see Bruce L. Egan, *Information Superhighways*, Artech House, Norwood, MA, 1991, Ch 2 and 7. For a more detailed discussion of broadband systems costs, see David Reed, *Residential Fiber Optic Networks*, Artech House, Norwood, MA, 1991; and for a broad discussion of topics, see Martin Elton, ed, *Integrated Broadband Networks*, North Holland, Amsterdam, 1991.

option for most service applications because bandwidth limitations and delay times make these technologies unsuitable for a multimedia real-time environment.[6] However, both radio and satellite are useful for infrastructure development in some applications. Satellites, for example, are preferred for delivery of distant video programming and may be interconnected to the wireline network infrastructure. But its use for voice service or other real-time two-way communications will probably be minimal.[7]

Microwave radio is useful and cost effective in many situations where fibre is not practical, such as over rough terrain or water. Many of the existing microwave facilities are useful for providing advanced telecommunications because they are digital and may feature high bandwidth and capacity for new service applications. However, for distribution of basic local service, both satellite and microwave will generally be limited to relatively high-cost applications. The Basic Exchange Telecommunications Radio Service (BETRS) approved by the Federal Communications Commission (FCC) is the primary application of microwave radio technology for local service and is expected to be the preferred alternative when wireline service is not feasible.

The best way to establish rural objectives for a network infrastructure is to begin at the state level. Telecommunications depreciation policy, basic rates and economic development planning are set at the state level; each state determines its objectives, timetables and financing requirements. There is an important gap in telecommunications infrastructure planning in most states, especially regarding coordination with the important transportation and energy sectors. We find the synergies of telecommunications network providers and public power grid operators to be underutilized for fibre-optic transmission and recommend more cooperation in this area. The same is true, but to a lesser extent, in the case of the transportation sector. The early beneficiaries of more cooperation between these sectors are rural education, health care and income growth.

What is rural?

There is no standard definition of rural telecommunication subscribers; however, some general observations should be made. First, 'rural' must be distinguished from 'remote' subscribers, meaning those whose access to the telephone network is non-existent due to physical 'remoteness' due to either distance or terrain. While they represent potential subscribers, for public policy purposes they should be separated from the general body of rural subscribers. Policy must be able to focus on upgrading communication infrastructures for those customers already hooked up to the network regardless of policies for reaching customers who are not only rural, but physically remote. Policy debates over remote non-subscribers can derail progress in technology adoption for the vast majority of rural subscribers.

There are few truly 'remote' subscribers relative to the base of all rural subscribers. One recent estimate puts the number of remote customers at 183 000, or only about 1% of all rural subscribers.[8] Many analysts designate the population outside of government-defined Metropolitan Statistical Areas, or 'non-MSA', as the rural population since the government is a convenient data source. Government statistics for non-MSA counties put the number of non-MSA subscribers at about 30

[6]For a discussion of multimedia demand trends see Egan, *op cit*, Ref 3, Ch 4, and the September 1991 issue of *Scientific American* which has several articles about the future of telecommunications networks.

[7]The round-trip transmission delay for two-way satellite service is 250 msec, which usually results in poor-quality voice conversations, though some researchers believe this problem could be mitigated somewhat using advanced electronics. In cases like rural Alaska, where customers never had a high-quality wireline option for voice service, satellite is more readily acceptable. However, the costs for voice satellite service in thin rural markets can be very high even when transponder capacity is leased from others (thereby removing up-front manufacturing and launch costs from the calculation). The delay does not present a serious problem for data transmissions.

[8]See Parker *et al*, *op cit*, Ref 2, p 67. This book classifies about 20 million households as 'rural' on a base of about 92 million households in the USA. Other estimates of remote subscribers appear in FCC Report No DC-1066, CC Docket 86-495, 'New Radio Service (BETRS) Established to Improve Rural Phone Service', 10 December 1987.

million, which represents a third of total telephone subscribers. Non-metropolitan counties are those with no urban areas greater than 50 000 population, but there are many possibilities for classification errors. For example, there could be metropolitan areas close to the border of adjacent non-MSA counties, or there could be many towns of less than 50 000 each.

Fortunately, for actual telephone statistics and data on rural subscribers a wealth of information exists for small independent telephone companies from industry trade groups such as the United States Telephone Association (USTA), the National Telephone Cooperative Association (NTCA) and an agency of the United States Department of Agriculture, the Rural Electrification Administration (REA). Specifically, the REA provides investment and financial data for over 900 small telephone companies serving over 5 million customers in very thin markets. Thus for present purposes the REA data will be representative of 'rural' subscribers. While many other data sources will be used in this analysis, the basis for most per-subscriber results will be the REA data.[9] Depending on any definition of the size of the rural subscriber base, the per-subscriber results contained herein may simply be increased by an appropriate factor to arrive at universe results.

Beyond the distinction of rural versus remote, there is also an important distinction between existing and new customers. Costs of technology adoption may be very sensitive to the fact that the necessity of starting from scratch in some areas renders moot the issue of whether or not to use some of the existing facilities in a network upgrade. For most subscribers a network upgrade must consider the embedded base of technology to ensure a cost-effective construction decision.[10] Keeping in mind the distinctions between rural versus remote and existing versus new subscribers, this analysis concentrates on the cost of network upgrades for existing subscribers – the vast majority. Remote and new subscribers will be considered separately.

Financial profile for rural telephone companies

There are over 1300 telephone companies in the USA, over 900 of which are borrowers in the federal government REA financial assistance programme. The top 25 local exchange carriers constitute over 90% of the total 130 million access lines.[11] All other telephone companies are quite small by comparison. Despite the great differences in physical plant characteristics between large and small companies, the financial and investment data are surprisingly similar when comparing average statistics.[12]

On average there are about 6000 access lines per telephone company central office. Bell Telephone companies have about 10 000 lines per central office and serve about 80% of the market with about 50% of all central offices.[13] Independent companies, on the other hand, have only 2350 lines per central office. REA borrowers, considered very small independents, average only 2500 lines per central office. In 1988 REA companies served 5.3 million access lines, approximately 4% of the total industry (for all 913 borrowing companies). Large telephone companies have average subscriber loop (access line) lengths that are about half that of REA companies (10 787 ft *v* 20 330 ft).[14] Finally, while Bell Telephone companies average almost 130 subscribers per route mile of outside plant, REA companies average just six.[15]

[9]The source of financial and investment data for small telephone companies is: REA Bulletin 300-4, *1988 Statistical Report, Rural Telephone Borrowers*, US Department of Agriculture, Washington, DC, 1989.
[10]See Egan, *op cit*, Ref 3.
[11]Detailed market data on these companies may be found in Bruce L. Egan and Leonard Waverman, 'The state of competition in US telecommunications', in Barry Cole, ed, *After the Breakup*, Columbia University Press, New York, NY, 1990.
[12]Due to space constraints the detailed network and financial data for these small companies are not presented, but they may be obtained from the author in the complete paper, *Bringing Advanced Telecommunications to Rural America: The Cost of Technology Adoption*, report prepared for the US Congress, Office of Technology Assessment, Research Working Paper 393, Columbia Institute for Tele-Information, New York, NY, October 1990.
[13]*Telephone Statistics for the Year 1987*, Vol 1, United States Telephone Association, Washington, DC.
[14]Schrage, *op cit*, Ref 4.
[15]REA, *op cit*, Ref 9; and NTCA, 1989.

Even with such striking differences in physical plant parameters, REA company investment per access line is only about 20% higher than for large telephone companies. The exact reasons for this are not known. However, the ratio indicates a significant cost efficiency relative to large companies with their short-loop, high-density plant. Overhead, toll operations and other specialized plant costs represent proportionally more of large companies' total cost, partially explaining the surprising investment and expense data.

Total book cost per line is $2288 for REA companies and $1881 for the top 25 local companies. Interestingly, REA companies have depreciation reserve percentages somewhat higher than the top 25 local carriers and their net plant cost per access line is only 14% higher. Relationships in rates of capital spending and total investment per subscriber for large and small telephone companies have remained fairly constant since divestiture (1984), which represents an aggressive network upgrade period for both. Another interesting category for comparison is annual expense per subscriber line. REA companies' expenses average $522 each year, while large companies' expenses average $558.[16]

Despite the large companies' ability to take advantage of engineering economies of scale in network equipment, small REA companies seem to exhibit greater efficiency; this has significant implications for the ability of small rural telephone companies to finance network upgrades to meet the requirements of an advanced network infrastructure. Of course, some reasons for these relatively low costs of REA companies are the low costs of REA financing and the savings from arrangements to share large company toll facilities and traffic and billing systems. In other words, some small company operations may be treated as operating expenses while the same activity for a large company may require capital outlays.

Nevertheless, even operation and maintenance expenses per line are consistently and significantly lower for smaller companies.[17] Large companies may incur relatively more costs due to the mobility of the access line base (access line inward and outward movement, or 'churn') and the tendency for service quality to be higher on large company loops (but which are also shorter, implying lower costs). Churn alone may not completely explain the difference in expense per line. Labour costs for both craft and management functions are much smaller for rural telephone companies. However, the fact that loop costs depend heavily on resource costs presumably favours large telephone companies with volume purchasing economies.

Financial data for large and small telephone companies since 1984 were examined, including revenues, cash flow, debt ratios and rates of return. These data are valuable for assessing the companies' capability to finance network upgrades and indicate very good financial health, providing strong support for aggressive modernization programmes, if regulators allow this situation to continue. While total industry revenue growth is sluggish, about 5% per year, cash flow (net income plus depreciation) remains high and growing. In fact cash flow for REA companies is 36% of total revenues compared with 29% of the industry average for large local telephone companies. During the post-divestiture period both large and small telephone companies had high cash flow due to significant increases in depreciation rates and large tax reductions. Debt ratios for telephone companies have been falling,

[16]REA, *ibid*; and *Telephone Statistics for the Year 1988*, United States Telephone Association.
[17]USTA, *ibid*, Vol 2.

increasing their ability to use debt financing for new construction. Rate of return on net capital (calculated here as net income divided by total invested capital) is high relative to historical rates. Revenues per line for small companies are $682 per year or $56 per month; the comparable figures for large companies are $757 per year or $63 per month. The difference can be attributed to the large companies' higher proportion of business access lines, which generate proportionally more revenue than residential lines. Thus average monthly charges for residential customers are similar for both large and small companies.[18] Both REA and Bell companies obtain about 10% of their revenues from non-network activities. One significant difference is that 56% of all independent telephone company revenues (64% for REA companies) is derived from toll service and toll carrier access charges, compared with only 46% for Bell companies.

Rural customers tend to spend proportionally more on toll service than urban customers. Carrier access charges and toll settlements paid from larger telephone companies to smaller ones increase the ratio of toll and carrier access revenues. As competition in the industry for toll and carrier access services escalates, this important revenue support for small telephone companies is increasingly at risk. The fact that some very-high-cost rural telephone companies depend on interstate toll subsidies for their existence represents a special problem for the future. For such companies, average loop costs can easily run three times the overall rural average.[19] Of course this also implies that some other companies operate well below the average.

Rural telephone plant characteristics

There are significant differences in the physical characteristics of rural and urban telephone plant. REA companies' markets are very thin, averaging only four subscriber lines per square mile of area served and only six lines per route mile of telephone transmission plant. For large telephone companies the density of subscriber lines is usually greater by at least an order of magnitude.[20] Bell has significantly more business access lines with an average length much shorter than for residential lines. Bell loop lengths average about half that of REA companies. The average loop length for REA companies is 20 330 ft, which is significant considering that access lines longer than 18 000 ft usually require special treatment to ensure high-quality basic service. The main problem is the attenuation of the analog signal, which may require boosting, using repeaters and amplifiers, or passive reduction of attenuation losses by loading coils, or both. Such loops are generally a problem for the new ISDN services that require relatively high-quality circuits for error-free digital transmission. However, the mode loop length is less than the average for REA companies. Consequently 55% of the loops are less than 18 000 ft. Of all REA loops 60% are actually non-loaded, but many still receive treatment of some kind to improve transmission and signal quality.[21] In contrast, 88% of Bell loops are less than 18 000 ft, and 76% are non-loaded with an average length of only 7500 ft.

Both large and small telephone companies have very long-tailed distributions for loop length, and the averages are sometimes misleading. Nevertheless, the average statistics for loop length, transmission electronics and investment are important for evaluating the average cost of loop upgrades. There is a great disparity between the tasks confront-

[18]For detailed data and discussion on post-divestiture trends in rural telephone subscriber rates and costs, see Joseph P. Fuhr, 'The effects of the divestiture of AT&T', and 'Rural telephony since divestiture', draft, Widener University, Philadelphia, PA, 1990.

[19]For a description of a very-high-cost rural company's experience and how it is dependent on toll settlement subsidies, see 'RTC – pioneer in today's West', *Rural Telecommunications*, Winter 1989. For some data on high-cost rural telephone plant and subsidies, see Fuhr, *op cit*, Ref 18.

[20]Detailed data for subscriber loop characteristics for both Bell and REA companies are available in Egan, *op cit*, Ref 12, Table 4.

[21]Schrage, *op cit*, Ref 4.

ing Bell companies and REA companies to upgrade their loop plant to ISDN compatibility. Although bridged taps limit the ability of loop plant to support new digital service, this is no longer a serious problem for REA companies, which have been reducing them in recent years.

Investment data for telephone plant in service for REA companies and the top 25 local telephone companies were examined: as expected, the investment in loop transmission facilities is in relatively higher proportion for REA companies. Interestingly, REA companies, while serving proportionally more of their subscribers with old step-by-step mechanical switching technology, have a higher proportion of lines served with advanced digital technology (45%) compared to Bell companies (30%) and the 10 largest independents (41%).[22] This has important implications for network upgrade decisions. On average, step-by-step switches are much older than the stored program control 1AESS and crossbar electromechanical switches which serve many of the Bell access lines; therefore the step-by-step switches of smaller companies are closer to economic retirement and should be converted to digital in any upgrade situation. Consequently small companies may have an advantage over large telephone companies who must consider the financial effects of early retirements of their embedded base of electronic analog and electromechanical switching plant.

The situation is quite the reverse for loop and transmission plant. Over one-quarter of transmission plant for small companies utilizes buried 'non-filled' cable that may not support ISDN. Although this type of cable may be nearing retirement age,[23] per-subscriber costs for replacement are quite high.

Existing versus new subscriber plant

For decades dramatic advances in network technology for providing toll service have lowered unit costs substantially. In the last decade some significant advances have been achieved in loop plant technology. Before the AT&T divestiture investment per access line for both large and small telephone companies was rising substantially; since divestiture it has been more stable. In the previous two decades there was significant inflation in materials and labour costs, and access line growth was relatively high. This explains some of the recent stabilization in loop plant costs. However, the relatively low real costs for access lines are mostly due to the introduction of the serving area concept in current plant designs. The serving area design concept was introduced by the Bell System and adapted for use in rural areas by REA companies in the mid-1970s. This design concept arranged logical groupings of subscribers who would be served by relatively short and large pair-size distribution cables from an intermediate field location called a Serving Area Interface (SAI) point. Relatively long feeder cables connect the SAI to the central office switch. Subscriber circuits are created by 'cross-connecting' wires from the feeder and distribution cables at the SAI points. Two significant developments in loop technology – the introduction of loop carrier systems and digital remote electronics and switching technology – helped implement this design concept. Loop carrier systems concentrate access lines by combining many customers' lines into one or more shared trunks. Previously each customer had required a dedicated (non-shared) loop.

The introduction of digital switching reduced the amount of dedicated loop plant by allowing remote nodes to be connected to the host digital

[22]Parker *et al*, *op cit*, Ref 2, p 79.
[23]See Schrage, *op cit*, Ref 4.

switch. Because of further advances in loop technology and other impending developments, real costs of rural telephone loops will decrease over the next decade. Significant advances in loop electronics and fibre optics are essential for future cost economies. Also, system growth is expected to decrease because of continual improvements in telephone penetration rates. This is not to imply that serious pockets of unserved rural areas are not a problem, but that the outlook on the cost side for the majority of subscribers is favourable due to advancing technology. Physically remote subscriber loops create special problems for engineering; due to vast differences in topology for any given subscriber there is no least common denominator. The possibilities are countless, preventing the adoption of a standard loop architecture. Engineering for high-quality service should be on a case-by-case basis.

Based on the average loop and digital central office plant parameters presented previously – roughly 4 miles in length with 2500 subscribers per digital central office – the average cost of a new rural access line is estimated to be $2500. This broad average assumes the use of digital remote terminals utilizing fibre-optic feeder trunks connected to the host CO with normal twisted-pair copper for the remaining subscriber distribution plant.[24]

Advanced rural networks

Much progress has been made in digital telecommunications technology for rural applications. As the economies of scale from this technology are utilized, per-subscriber costs for digital switching continue to fall. This technology, more than any other, will allow rural subscribers to take advantage of new information age services including on-line computing, database, information and transaction services, remote monitoring, advanced facsimile and data services. These are the primary near-term applications for advanced rural telecommunications that will enable subscribers to 'telecommute' or improve their productivity in the office or the home. Eventually broadband digital service will become possible for anything from still pictures and high-speed graphics to full motion entertainment video.

Basic narrowband digital service begins with upgrading rural network functionality. Initial upgrades will support only low-speed data and voice service. Expanded network capability will support higher data rates from 56 Kbps service up to 144 Kbps full ISDN service. This is the same migration scenario as is scheduled for urban networks. In both urban and rural areas business customers may require broadband services while residential customers will probably be satisfied with narrowband capability.

Developing and deploying advanced digital telecommunication networks is a difficult and costly proposition, even in dense urban and suburban areas. Narrowband digital service, in the form of ISDN, has been in the implementation stage for several years now; however, there is still no residential service and very limited access to business service. With widely available residential ISDN service not expected until late this decade, it is clear that even more advanced network upgrades will be delayed for both physical and financial reasons.

A major problem with narrowband digital service network upgrades, as with next-generation broadband services, is that there are no significant demand drivers, primarily because network services, almost

[24]A stylized view of the average subscriber line appears in Egan, *op cit*, Ref 12, Figure 4. This stylized loop could support narrowband digital services (56–144 Kbps).

by definition, require two-way end-to-end connectivity. Yet physical network upgrades are only gradual processes where more and more customers obtain access to the new technology over many years. It takes a long time to implement widely available interconnectivity, the factor that will provide the demand-pull for further technology adoption.[25]

Business subscribers

The rapid development of an advanced communication infrastructure for rural America will depend on how easy it is for businesses to access the technology. Businesses consider telecommunications capability an important factor in their location decisions. To the extent that businesses will have advanced services available to them, rural areas may become more attractive locations. Furthermore, as telecommunications capability improves in rural areas, demand-pull will begin to stimulate further technology adoption as businesses and their various suppliers and customers make use of more efficient network facilities. However, exactly what constitutes advanced telecommunications for businesses is an unsettled issue.

Relatively large businesses in rural areas, whether in the service or manufacturing sector, often require broadband communications capability to maximize operating efficiency and keep up with their urban and suburban counterparts. Broadband in this case refers to digital transmission speeds of 45 Mbps and higher. At such speeds high-quality data services and video telephony are possible. Such transmission speeds are much greater than the narrowband ISDN service which is currently being deployed. Broadband service generally requires fibre-optic facilities, while narrowband service may be provided over more traditional copper facilities. Microwave and fibre technologies are capable of supporting both narrowband and broadband services but, as already explained, fibre is expected to be the dominant medium in the future.

Since fibre optics not only allow for future broadband telecommunications and simultaneously provide for integrated narrowband services, there is some question as to whether incurring the costs of narrowband ISDN on copper facilities is worth it in the long run. Some analysts believe early deployment of broadband fibre-optic facilities is the way to go, bypassing the deployment of narrowband digital service on copper. In the case of business customers, the author tends to agree with this position. Even though most well-known business customer services may be provided on narrowband digital facilities, very-high-speed data and full motion video telephony will require fibre-optic facilities.

Rural economic development partially depends on attracting businesses that require efficient telecommunications. Thus the focus should be on getting fibre optics deployed in the public network as far downstream as possible, so that business customers have the option of accessing the network for high-speed service applications, should the need arise. It will not be necessary to subsidize business access to the fibre-optic public network, but it is important that they have a cost-effective option to build or lease their own access lines to a high-speed digital public network, since this option usually exists in urban and suburban settings. The way to do this is through an aggressive statewide plan for a fibre-optic network infrastructure.

Residence subscribers

The deployment of advanced rural telecommunication facilities for

[25]David Allen discusses the problem of reaching a demand-pull threshold in his article 'New telecommunications services: network externalities and critical mass', *Telecommunications Policy*, Vol 12, No 3, September 1988, pp 257–271.

residence subscribers should be viewed in several stages. Dedicated fibre-optic access lines are generally not required to support the demands of residential customers. As noted previously, fibre optics are cost effective in shared-use applications typical of business subscribers. For residence subscribers network capability for narrowband digital service should be the first priority because it can support most known end-use services, such as computing, database services, and imaging and video services up to the T1 rate (1.5 Mbps). Achieving this objective requires two things: upgrading older central offices to provide digital switching capability, and upgrading subscriber loop plant to provide digital transmission with low error rates.

The cost of upgrading rural subscribers to digital central office switches is estimated to be about $2.5 billion or $250 per rural subscriber.[26] This is not beyond the financing capability of the average rural telephone company, even at existing subscriber rate levels. REA companies have about 5 million subscribers; assuming half need to be upgraded to digital switching at $250 per subscriber,[27] the total upgrade cost is about $625 million. Current REA company total annual cash flow is over $1 billion, and construction spending is also estimated at about $1 billion.

Upgrading the loop plant of rural telephone subscribers for digital service presents a greater financial dilemma. A high percentage of existing subscriber loops cannot support an acceptable level of digital transmission, even for existing services. Regular voice telephone service requires much more bandwidth in digital form than in analog form. Current loops are engineered to support analog voice at 3–4 KHz, and very-low-speed data service up to 9.6 Kbps. To attempt more than this risks intolerable errors in transmission. Thus the motivation to upgrade the rural loop plant is that current bandwidths will not support the use of many new service applications.

It would be misleading to conclude from the data on rural company loop investment that the upgrade problem is simply solved over time by the replacement of investment through rapid depreciation. Increased cash flow from depreciation, an important source of funds for new loop plant, also implies rate increases for current subscribers or increased subsidies from others, or both. In addition, the new loop plant is nominally more expensive than the old, even with technological advances, because of inflation in prices. However, new digital loop carrier systems can mitigate the higher current costs by significantly increasing sharing of loop plant capacity among many subscribers and cutting ongoing maintenance, resulting in lower future per-subscriber costs.

Generally, the main problem with upgrading rural subscriber loops to digital service is the presence of loading coils on about 40% of them. These must be removed by cutting out the load coils and replacing the cable at the load coil point or, if suitable, loop carrier or remote switching terminal equipment may be installed. Normally this would be all that was required in the physical loop digital upgrade. However, rural telephone companies still have a substantial amount of buried 'non-filled' cable in their loop plant. This may not support high-quality digital service even at low speeds if moisture has penetrated the cable. Nevertheless analog voice is acceptable on non-filled cable. The financial requirements for upgrading 'gel-filled' cable rural loops for digital service are not too much of a burden for current telephone company construction budgets over a reasonable time period of 10 years or so.

[26]Assumes 20 million rural subscribers, with half already served by digital central office switches.

[27]In a recent study of switching upgrade costs for rural loops, 'Rural network modernization in US West', draft, 25 July 1989, Julio Molina and E. Reed Turnquist report average per-subscriber digital upgrades at $300–500 in one state and only $180 in another. They also state that a reasonable near-term target is as low as $150 per subscriber.

However, for 'non-filled' cable loops it is indeed costly, and an aggressive rehabilitation programme may require relatively heavy external financing. It would be very costly to rehabilitate the buried non-filled loop plant with gel-filled cable. The process of replacement should speed up since the remaining non-depreciated useful life of non-filled cable is relatively short (it was last installed in the early 1970s).

The estimated cost of upgrading rural loops to provide for narrowband digital service using filled cable is about $100–200 per subscriber. For non-filled cable the average cost could be as much as $2500 per subscriber. This only represents the average; some customer loops would be even more expensive to upgrade, such as where spatial distribution of subscribers was not conducive to sharing facilities. One goal of the upgrade, de-loading rural loops, could be very expensive when there is no cost-justified possibility for shortening the dedicated portion of the subscriber loop through the use of a remote subscriber terminal (RST) or digital loop carrier system. The loop architecture for the average subscriber above assumed that a fibre trunk connected an RST to a digital host central office and filled distribution cable. Where no RST is available one must be installed. Thus fibre optics and fibre-compatible RSTs are the primary features of state-of-the-art rural loop upgrades.

For situations where it is simply too expensive to use the recommended loop architecture, there are several alternative choices including satellite, existing coaxial cable television links, radio and cellular radio. These alternatives must be evaluated on a case-by-case basis, including an estimation of the cost of an efficient connection to the public wireline network.[28]

State infrastructure

Today's rural telecommunications infrastructure is a patchwork quilt of subnetworks with many owners and operators, featuring a broad spatial distribution of network facilities. Though this situation may be locally efficient for telephone subscribers because of technical efficiency and good customer service in very diverse, thin local markets, it is probably not globally efficient from an infrastructure perspective. The main area for improvement is coordinating regional communications activities; and correcting inequalities in customer service options and capabilities across geographical areas of the state is also a top priority. With good coordination these problems are not necessarily expensive to overcome.

The infrastructure approach to state telecommunications planning minimizes the deployment costs of advanced public networks by taking advantage of potential synergies among public and private network investments. Compatibility and easy interconnection between public and private communication networks may favour technology adoption in cost/benefit calculations for investment in public network infrastructures. Rural economic development primarily depends on attracting new business to rural areas or stimulating expansion of existing businesses, a process that is more likely to occur if preceded by a high-quality communications capability, for both internal and external use with suppliers and customers.

Part of the key to more rapid economic development in rural America is for policy makers to view telecommunications as an enabling factor in the planning equation for attracting business. The payoff for any state

[28]Many case studies of alternative loop technologies are provided in Egan, *op cit*, Ref 12, Section 5.

will be much greater if businesses drive the development process. It would be of limited value if investment in advanced telecommunications for residence subscribers were undertaken before that for business subscribers. The approach recommended here gives first priority to investment in the shared public network infrastructure, so that wherever business may ultimately choose to locate they will not be far from a point of interconnection to a high-speed digital public network node. The preferred window of technology deployment for high-speed digital networks for businesses is 1–5 years, while for residence subscribers it is 5–20 years, depending on location and local telephone plant characteristics. Hence business demand drivers will ultimately speed the process of technology adoption.

The available data for rural areas indicate that there are many communication networks and facilities, some quite advanced, that are not being used efficiently from an infrastructure perspective. Many private, public and quasi-public networks have a variety of specific communications applications which could support infrastructure development for an entire state or region if efficiently interconnected to the public switched telephone network.

Other authors, noting this inefficiency, have recommended that state planning and development agencies be empowered to at least study infrastructure coordination, make recommendations for development, and perhaps provide expert assistance and financial support to infrastructure firms.[29] This author thoroughly agrees and recommends that such coordination take place at the state level, which is where regulatory and planning authority lies. It will be critical that the state regulatory authority is included as a major player. This is, after all, the only state authority that may legally demand prompt compliance with standards, monitoring and reporting requirements. Good data are critical to good planning. Proper coordination and planning can generate many possibilities for relatively efficient communication infrastructure development in rural areas. Currently, pockets of advanced communication capabilities occur in private and quasi-private local networks, without due concern for how they contribute to overall infrastructure development.

For example, educational communications over fibre-optic and satellite facilities in closed networks are often not interconnected to public telecommunication networks.[30] As another example, many high-capacity intercity networks use microwave and fibre optics for large customer applications and have substantial spare capacity running through rural areas. This would present a net revenue opportunity for the owners of such networks if they were interconnected to public network facilities. Interconnection possibilities include tail-end microwave hop-on and hop-off, and fibre interconnection from urban drop-off points. However, no one is charged with the responsibility of investigating such possibilities; and in many cases the owners and operators of such specialized networks do not have the time, responsibility, foresight or expertise to evaluate interconnection possibilities.

Because the social benefits of efficient public telecommunications networks exceed the sum of private benefits, the initiative to bring together public and private interests must come from the government. Recent experience with private sector competition and telephone deregulation indicates that the public telecommunications infrastructure is increasingly fragmented due to the proliferation of private networks utilizing a host of technologies and due to the incompatibility of

[29]This is the recommendation of Parker *et al*, *op cit*, Ref 2.

[30]For a summary of education networks and systems, see Office of Technology Assessment, *Linking for Learning*, OTA, Washington, DC, November 1989. See also *Interactive Television: Technology Linking Rural America*, Technical Paper No 2, Opastco, Washington, DC, December 1989. More examples of the use of fibre for interactive video learning are found in the Minnesota Educational Telecommunications System, where public education joined up with rural telephone service providers: see 'Minnesota independents tune into fiber opportunities', *Roundtable*, Winter 1988. Rural Oklahoma's Panhandle Telephone Cooperative also provides extensive educational telecommunications on a fibre network, described recently in a talk by Gary Kennedy, Panhandle Telephone Cooperative Inc, Guymon, OK, presented at the Fifth Conference on State Telecommunications Regulation, 22 January 1990, Salt Lake City, UT.

proprietary devices, interfaces and protocols. In this setting, private industry groups are slow to reach agreement on infrastructure issues such as standards, interconnection and public network efficiency. This is understandable because much of the private networks represents a large, as yet unrecovered, investment in proprietary communications systems.

However, businesses do understand the importance of efficient end-to-end service capability using both public and private network facilities. They would be receptive to public initiatives to coordinate and plan for infrastructure development, which would include setting specific timetables, and establishing efficient processes for creating network standards and trials for new technologies stressing easy interconnection and 'interworking' (interoperability across vendor equipment and network facilities). An example of such a public initiative, albeit one for mostly urban applications, is the recent New York State Department of Public Service plan for ISDN development.[31]

Fibre optics

The implications of digital fibre-optic technology for infrastructure development are profound. For the first time a dielectric, low-cost, high-capacity, reliable communications medium is available to support the future communications requirements of rural America.

Due to its revolutionary nature as a new communications paradigm, many telecommunications engineers overlook the potential of digital fibre optics for rural applications. The same is true of many radio applications.[32] Even though fibre is relatively costly to deploy for dedicated subscriber loop plant, the use of fibre optics in shared plant facilities is more cost effective than most alternative technologies whenever two-way real-time service is required. Two-way real-time capability is central to the future of advanced telecommunications. The major cost factor for fibre optics, as with most wireline technologies, is trenching for underground cable and conduit, which is generally preferred to aerial construction because of aesthetics, extension of service life and reduction of maintenance costs. Since trenching is so expensive it may be avoided by less expensive construction methods such as direct burying, ploughing or aerial construction. This type of construction will not present a burdensome cost compared to similar installation costs of traditional copper-pair cable.

The major cost and expense problem at present is the optical/electronic interface equipment at the ends of the fibre-optic circuit, especially at the subscriber end. Fibre-optic cable splicing and electronics costs are relatively high, but rapid progress in reducing such costs continues and they will probably not be a limiting factor over the long term.

The use of a dielectric transmission medium, such as fibre optics, provides an unprecedented opportunity for inexpensive infrastructure development by taking advantage of new-found synergies of combining existing electric utility distribution infrastructures with that of telecommunications. Construction costs of fibre-optic facilities may be substantially reduced by utilizing public power grid rights of way and pole or conduit facilities. Since optical transmission is not susceptible to electromagnetic interference caused by power lines, fibre cables could use the distribution plant offered by the statewide power grid by purchasing or leasing facilities from rural electric utilities. Such inexpensive fibre

[31] *The ISDN Trial in New York State*, New York State Public Service Commission, report, 15 March 1990.
[32] Some of the aversion that rural telephone companies have to delivering POTS via electronic carrier frequency is probably due to the fact that, in years past, some service was provided on buried cable loop carrier which performed poorly. Such memories of service failure die hard. The other reason is that an unfamiliar loop technology causes craftspersons to be uncomfortable with it, and their lack of training increases its maintenance costs.

deployment may even include lashing the fibre cable to the electric utility ground and phase wires, which often run along the tops of towers and poles. There are many possibilities. One new product on the market is a fibre cable which utilizes the metallic ground wire for strength.[33] The ground wire in the cable supports the requirements of electric utilities, and the fibre communications capacity may be resold.

Power companies are heavy users of communication services, and many large utilities already operate major private communication networks. Smaller rural electricity companies also require communications for load management, monitoring, internal communication and the like. Rural electricity cooperatives serve geographically large and thin rural markets which often span many independent telephone company exchanges. Because they cannot justify 'stand-alone' internal communication networks, small electric utilities must rely on many rural telephone companies, and pay relatively high tariff rates. The sharing of power company facilities with local telephone companies can provide economies for both, providing a 'win-win' situation. In addition, some large businesses choosing to locate in rural areas are often unable to get sufficient power, while advanced communications capability is lacking. If the shared infrastructure were available, businesses might be more likely to locate and expand in rural areas.[34] Safety communications for fire and alarms are other new service applications which place only nominal bandwidth requirements on the communications infrastructure. There seems to be a natural synergy here for rural communication infrastruture development, but one that is underexploited. The electric power industry tends to be conservative, but many firms are now examining novel arrangements with communication service providers. To help spur such cost-efficient developments in the use of fibre optics the Electric Power Research Institute is beginning to develop industry standards, and the Tennessee Valley Authority is actively pursuing some of the possibilities.

Rural telephone companies, long desirous of entering directly into the lucrative toll market, could begin to take advantage of the revenue opportunities that a fibre-optic infrastructure could provide, not to mention the possibilities for providing new data and video services which fibre optics can support. This is very important if it is true that traditional large telephone company toll subsidies enjoyed by small rural telephone companies will eventually disappear due to increasing competition. Small rural telephone utilities may pool traffic and interconnect with the fibre-optic backbone trunk network to provide high-quality toll voice and data services efficiently and profitably. Fibre-optic backbone networks may also allow rural subscribers to purchase digital services and access remote databases of enhanced service vendors.

The process of rural telecommunication infrastructure development is an evolutionary one that will occur gradually as advanced facilities become available. For this reason it is important that the process begin as soon as possible. State telecommunications planners must take on the role of coordinating network interconnection and development activities, exploiting potential synergies for the benefit of all subscribers. In the early stages such coordination will concentrate on surveying all the communication facilities, public and private, and evaluating short-term and long-term interconnection and compatibility potential. At first, microwave and satellite network facilities will be evaluated, along with existing coaxial cable network facilities, to determine interim infrastruc-

[33]See Charles R. Russ, 'Composite optical groundwire – design and economic considerations', unpublished paper, Alcoa Fujikura Ltd, 7 June 1988.
[34]Such real-world considerations were expressed by Ralph Minor of Pal Valley Electric Coop in Jonesville, VA, a small but widely dispersed rural utility (private correspondence).

ture possibilities. The long-term focus will be on migrating to a more efficient infrastructure based on digital fibre optics and radio technology; the goal will be to share network facilities whenever it is cost effective to do so, and guide the replacement of older network facilities with advanced facilities, stressing network compatibility along the way. Without compatibility, interconnection of communication networks will be inefficient or even impossible, and potential synergies will be lost.

The rate of development of rural telecommunication infrastructures may depend largely on demand drivers. There are some logical ways to pursue network technology adoption, paying close attention to demand patterns in the current infrastructure. For example, secondary and tertiary schools, libraries, hospitals and regional airports tend to be among the heaviest consumers of information and telecommunications services in rural areas. Public power utilities and other rural infrastructure firms, including occasional large manufacturing or service companies, also represent logical node points for rural networks. Existing telephone company switching offices, combined with the aforementioned, represent demand drivers and potential network hub sites, providing for efficient communication infrastructures. This set of candidates for network node (hub) points should allow for a number of alternative deployment scenarios for state telecommunications planners to consider. Hubbing allows the economies of satellite, microwave and fibre transmission to be used cost effectively in relatively thin markets, thereby maximizing the net present value of the rural construction programme.

Regulatory issues

Planning for an advanced rural telecommunications infrastructure raises many regulatory and public policy issues. Prominent among them are: Who should own and control the infrastructure, and how should it be financed? There obviously are no 'right' answers to such questions, but some general economic principles may guide the thinking on these issues. First, private ownership and control are generally preferred to public ownership and control, for reasons of operating efficiency incentives that competition provides.[35] Second, government must have a proactive role as an overseer, enabler and planner. As discussed previously, private network development may help support infrastructure development in a 'win-win' situation where net revenue opportunities accrue to both private and public network participants through efficient interconnection and compatibility. This is where the role of state government may be most helpful, identifying where public and private communications network activities may complement each other and strengthen the overall infrastructure.

As a rule, an infrastructure approach does not imply centralized ownership or control. It does imply cooperation among the various players, however, and this is the enabling role of government – bringing together the players and encouraging infrastructure development. Much more can be done than we observe today. Most states have not yet placed sufficient emphasis on telecommunications infrastructure and its role in economic development, even in rural areas. New technologies just beginning to be deployed have very low unit costs once demand thresholds are met, but have very high up-front capital costs. For this reason an infrastructure approach to planning, which maximizes capacity sharing through a 'hubbing' network architecture, holds great

[35]Many rural electric utility cooperatives are very successful operations, thus publicly owned and operated arrangements are not necessarily worse than strictly private ones.

promise for dealing with the problem of thin rural markets. For example, even in Kentucky, considered a rural state, there are many existing locations which could generate enough traffic demand to justify a fibre, radio or satellite hub, depending on the specific demand application(s) required.[36] Eventually fibre hubbing would dominate as the technology of choice for most new shared network applications, while microwave radio, coaxial and copper cable will be used for dedicated short-haul subscriber plant, with satellite and microwave radio utilized whenever wireline facilities cannot be deployed cost effectively, especially in physically remote applications.

Finally, there are a host of important pricing issues associated with recovering the costs of advanced telecommunications infrastructure development. Two primary ones are broad toll rate-averaging across the nation and toll-to-local service subsidies. Trends in both of these areas are troubling for rural telephone companies and will no doubt become the subject of extensive public policy debates. A full discussion of these issues is beyond the scope of this article, but a few observations deserve brief discussion.

Increasing competition in toll services and the absence of regulatory rules for retail tariffs of competitive toll carriers are slowly eroding the broad rate-averaging rules which have been in effect for many years. The effect of rate averaging is to subsidize subscribers in thin rural markets relative to those in dense markets. New volume discounts for heavy toll users, especially business customers, have already been undermining traditional rate averaging. Regional rate de-averaging is likely to occur eventually. The toll subsidy which flows generally from larger telephone companies to smaller ones is also going to decrease as competition continues to drive prices down. The best solution here is probably to target subsidies more carefully towards only those companies that need it most instead of towards entire classes of small companies as is currently the case.[37]

Financing alternatives

The deployment costs for efficient communication infrastructures are high compared to any historical measure of the costs of technology adoption. The reasons are twofold: the technological trends are towards lower ongoing usage costs, and higher up-front capital costs. Digital network equipment has few moving parts and features very-large-scale capacity relative to older-generation network equipment. As such, the new equipment is more cost efficient from a maintenance and repair expense perspective, but is more capital intensive and is typically purchased in greater 'lumps', because it is well suited for large-scale operations. The same tends to be true of fibre-optic transmission equipment, although for many network applications fibre will soon be cost effective even relative to the older-generation copper and coaxial cable costs. The bonus with fibre optics is not only its very high capacity but also its high quality and reliable service as compared to metallic and radio technologies. Nevertheless up-front deployment costs for fibre optics are substantial, and every effort to introduce it cost effectively is important.

Telephone rates are the obvious first choice for financing advanced rural network infrastructures; indeed, most of the financing must come from this source. Fortunately, under the traditional finances of telephone utilities it appears likely that internal capital flows will fund much

[36]For a more detailed discussion of the existing Kentucky infrastructure for power, transportation and telecommunications, see Egan, *op cit*, Ref 12, Section 6 and the Appendix.
[37]See Fuhr, *op cit*, Ref 18.

of infrastructure deployment costs. Borrowing is the next alternative to consider. The US Department of Agriculture's Rural Electrification Administration and Rural Telephone Bank (RTB) and others provide subsidized loans to rural telephone companies. Without government assistance these telephone companies would have to go to other capital markets that offer less attractive terms. There are other major sources of funds for telephone companies besides the Department of Agriculture, including Banks for Cooperatives (part of the Farm Credit System), the Rural Telephone Finance Cooperative and the National Cooperative Bank.[38]

Unlike large telephone utilities, many rural companies are already highly leveraged. This is not bad in itself, but it does affect the propensity of lenders to approve more funds on favourable terms. Regulators may also become concerned about the level of business risk which leverage implies, even though ratepayers may benefit from the lower average cost of debt capital relative to equity finance.

The REA, RTB and some other lender practices are basically sound for financing advanced rural telecommunications infrastructures because they operate within an incentive structure which tends to give the right signal to borrowers to make good investments. The REA and RTB use 'equity-based' financing and loans that are usually 'self-liquidating'. Furthermore, the proposed investments of borrowers must meet general technical guidelines for acceptable and approved equipment purchases. This system prevents speculation and abuse of government loan funds.[39] Even though the REA programme is a loan subsidy programme, only the interest rate discount is truly 'subsidized', and this is a relatively small portion of the entire loan and repayment sum. The loans are self-liquidating from revenues and cash flow from telephone rates. Overall this approach seems socially efficient since it allows the private sector to determine the market requirements and opportunities for sound investment decisions, and requires the borrower to have a substantial equity stake. The only government role is to provide an inexpensive source of funds, technical support and monitoring.

Direct subsidies, especially untargeted ones, would be much worse and are often not socially efficient. The current flow of toll-to-local subsidies from many large telephone companies to many smaller ones is generally inefficient because it is not based on need; instead, it is based simply on a grand formula for broad rate averaging and revenue sharing.[40] In fact, some of the vast sums of money in the toll revenue pool now divided among telephone companies through the use of a broad formula could be used to increase the REA's loan authority or could be distributed based on financial need. Whenever subsidies are not targeted there are potentially wasted resources. The introduction of basic telephone 'lifeline' service based on a 'needs' (income) test is a good example; this has proven to be much more socially efficient than a blanket subsidy for all local service subscribers, even for those who can afford it. As the financial data provided earlier indicate, many small rural telephone companies have very healthy cash-flow situations and do not really need subsidies.

Direct government subsidies for rural telecommunications should be discouraged since the investments funded will presumably generate some level of ongoing subscriber revenues and should therefore always be included in any loan repayment formula, even if the repayment is only a partial one.

[38]See 'Financing telco growth', *Roundtable*, Fall 1989.

[39]It is not perfect, and some REA loan abuses have occurred. However, this problem can be handled with more rigorous scrutiny of loan applications.

[40]See Fuhr, *op cit*, Ref 18, for a discussion of the subsidy flows in the current revenue-sharing system. There is little correlation between costs, financial need and subsidy flows, and no targeting mechanism exists in the current formula.

There are many other market-based financing possibilities, including revenue growth from existing and new services and advertising. Advanced rural telecommunications networks will be able to support a range of new services and lines of business for telephone companies. The most lucrative is toll and toll access services. Many rural companies rely largely on other vendors to supply toll and access services, including measurement and billing, for their local service customers. The high capacity of digital fibre optics is changing this situation dramatically. Now many small rural telephone companies can share fibre-optic facilities to begin to provide toll and access services. There are already many such operating arrangements.

Another potential high-growth market which digital rural telephony makes possible is data and computing services, including remote database access, transaction services, audiotex and videotex, shopping-at-home, etc. Ultimately revenues from providing entertainment video on fibre-optic subscriber lines will be possible.

Another revenue opportunity which rural telephone companies realize from new digital technology is advertising and telemarketing revenue. Vendors wanting to efficiently tap the purchasing power of rural consumers will be willing to pay for access to that market segment. Due to expanded bandwidth on residential telephone lines, advertising need not tie up the entire line. Shopping over the telephone can occur along with normal voice conversations using ISDN technology. In some novel advertising techniques, rural customers willing to let vendors advertise products which interest a particular household would actually receive a monthly subsidy from the vendor(s), reducing their telephone bills.

Conclusions

Perhaps one of the most important policy conclusions from the analysis presented here is a firm recognition that there is a notable difference between the costs of local network upgrades for the base of existing rural telephone subscribers, and the costs of serving brand new and physically remote subscribers. From a public policy perspective the latter must be treated as special cases requiring significant cost subsidies, otherwise policy for the masses could fall victim to debates of subsidies for the few. Overall, the existing body of rural subscribers is currently being served cost effectively and profitably, and a timely digital network upgrade is a reasonable proposition without necessitating large rate increases.

Secondly, the key to rapid adoption of advanced technology for rural subscribers is to take an infrastructure approach to the problem. This implies significant coordination and monitoring of public and private network investment and business activity, preferably at the state level. Specifically, in the current environment there appear to be significant lost opportunities for the realization of public benefits and potential synergies from cooperation of the energy, transportation and telecommunication sectors.

The infrastructure approach could go a long way towards solving this problem and actually follows from the technology itself. First and foremost, new telecommunications technologies can be very efficient, but that efficiency depends on two critical factors which are often non-existent in rural areas of the country: economies of scale and end-to-end service capability. The first factor operates on the supply side of the equation and simply says that technologies such as digital fibre optics require relatively large-scale operations to achieve the low unit costs which are ultimately available. End-to-end service operates on the demand side of the equation and simply says that unless advanced network functionality is adopted on a very wide scale, demand drivers will be unable to speed up the technology adoption process. It is no good to have ISDN service capability unless the other party to the call also has it. Thus the critical issue for efficient technology adoption in rural telecommunications is sharing of network facilities, both to achieve scale economies and to stimulate demand drivers.

Fibre optics is generally the most cost-effective technology for shared network service applications. Fibre is not cost effective for dedicated (non-shared) customer facilities such as residential loops. Most businesses, especially large ones, share network facilities among a number of telephones and therefore may cost-effectively adopt fibre technology before residential customers. However, both businesses and residences must share facilities as much as possible to take advantage of the superior economies of scale which fibre exhibits relative to competing technologies.

Another important advantage of fibre optics is that it can support new broadband services such as video telephony, multimedia services and very-high-speed data service. It is not necessary that demand for broadband services precede fibre-optic technology adoption because fibre is also very cost efficient for simultaneously transmitting narrowband services. Sharing and multiplexing allow fibre to become cost effective even when only narrowband service applications are used.

An infrastructure approach to rural telecommunications technology adoption should maximize the possibilities for sharing, thereby stimulating investment in those technologies offering the greatest cost efficiencies. The bonus with adopting digital fibre-optic technology early on is that the network will be robust with respect to almost any conceivable demand scenario that ultimately develops.

Research and development in telecommunications

National systems under pressure

Hariolf Grupp and Thomas Schnöring

Research and development activities (R&D) are becoming more and more important for the development of the telecommunications industry. To a large extent they determine the competitive position of firms and nations. Both the equipment and carriers depend on their technological competence. In the past, national R&D systems developed separately, and differed widely from one country to another. With the liberalization of the telecommunications markets and increasing international competition the different national R&D systems have come under pressure and have begun to change. This article describes the structure of national R&D systems at the end of the 1980s and analyses development trends. It summarizes the principal findings of an extensive study into the development of the national R&D systems of the USA, Japan, France, the UK, Italy, Sweden, South Korea, the Netherlands, Spain and the Federal Republic of Germany.

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This article summarizes earlier work by a team of seven researchers from ISI and two from WIK, published in German as H.
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Table 1 shows the extent of research and development (R&D) expenditure in 10 countries. First and foremost the levels of spending reflect the size of the countries' economies. It comes as no surprise, therefore, that the USA has by far the largest R&D budget, followed by Japan, the Federal Republic of Germany, the UK and France. The relative size of the budgets corresponds more or less to the national income ratios. All countries spend a noticeably large amount of their total R&D budget on telecommunications. This underlines the high priority currently granted everywhere to the telecommunications sector. The R&D endeavours of South Korea are surprisingly prominent following a strong expansion of its R&D efforts since the mid-1980s. This development indicates that Korean companies will feature not only as low-cost suppliers but also as innovative competitors in the future.

R&D expenditure in the military sector must be taken into account when examining civil telecommunications markets insofar as they trigger spillover effects for civil applications. Companies did cite spillover effects when interviewed, especially in connection with radio technology, but the general opinion was that the speed and direction of technological progress is being increasingly determined by the civil sector. This summary therefore regards the R&D budgets exclusively from the viewpoint of civil telecommunications.

Role of the common carriers

The size of the R&D budget of the common carriers and the degree to which their activities mesh with those of manufacturers, universities and research institutes vary greatly from country to country. Moreover, the carriers exert considerable influence by way of their procurement and standardization strategies as well as by other means.

Figure 1 shows the financial contributions of the carrier sector, which differ considerably, ranging from 60% in France to 7% in the Federal

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