PLANNING THE TELEPHONE HIGHWAYS

John M. Peacock, American Telephone and Telegraph Company

Organization of the telephone network in the United States has much in common with the system of local, state, and national streets and highways. There is a direct analogy between the various classes of roads and their counterparts in the Bell System network. Circuits are bundled together into blocks of various sizes depending on traffic demand. Telecommunications transmission is based on a hundred years of technological innovation. The millimeter waveguide system now under development at Bell Laboratories is expected to go in service in 1980 as the next stage of evolution beyond coaxial cable. It has a capacity of ¼ million voice channels and will become the backbone of the long-distance network. Waveguide resembles a rugged steel pipe. It has important advantages over coaxial cable from the standpoints of increased capacity, reduced need for maintenance access, and improved reliability. Virtually all coaxial cable routes are on private right-of-way. Land use and environmental impact might be minimized if waveguide were located on freeway right-of-way where the routing is coincident and where the right-of-way is adequate to permit economic construction without disruption to highway usage or safety. A joint study is proposed to evaluate the feasibility of this alternative.

•THE ORGANIZATION of the communication network in this country is remarkably analogous to that of the transportation system. There are many similarities in physical structure. Also, both fields are continually changing and evolving as new technology and new constraints are introduced.

This paper briefly reviews the history and present state of the art in telephone transmission. This background sets the stage for a description of the new waveguide transmission system, which is in advanced development now and scheduled for commercial service in the 1980s. This is a very high-capacity system for major long-haul routes.

Can waveguide routes share right-of-way with limited-access highways? A joint study is proposed to evaluate this alternative.

EVOLUTION OF THE TELEPHONE NETWORK

The first telephone call in 1876 was from one room to another room just a few steps away. For several decades thereafter the major thrust was to extend the feasible transmission distance. Range extension was achieved during the years through a series of inventions such as the vacuum tube amplifier and improved transmission lines. In 1915, after 40 years of telephone development and a lot of hard work, the first transcontinental line was completed. This line had 3 circuits!

In the years since, major emphasis has been on technological innovation to improve the traffic-handling capability and economy of the system. It is a giant stride from a few dirt roads to the 40,000-mile Interstate highway network. Exactly the same thing could be said about the communication highways. The first circuits were hard-pressed to carry intelligible conversation; today long-haul telecommunication systems have capacities in the hundreds of thousands of channels. Human voices can be intermingled with music or computer talk at will just as midget cars can share the highways with tractor trailers. The carrier techniques that make it possible to stack the signals up in this way represent the most advanced state of the art in electronic technology. Table 1 gives the dramatic increases that have been achieved in capacity.

Table 1. Transmission system capacities.

	Voice Channels		
Decade	Cable	Microwave	Waveguide
1930	480	–	–
1940	1 800	–	–
1950	5 400	3 000	–
1960	32 400	22 800	–
1970	108 000	25 800	–
1980	–	72 000	250 000
1990	–	–	500 000

So far we have discussed only the development of transmission technology. Of equal importance are the strategies for physically organizing and interconnecting the network so that any of the 125 million telephones in the United States can reach any other one in a matter of seconds. The circuits originate at those places where customers request service. The individual telephones are connected to the exchange network, which converges on the local switching center through a well-organized system of distribution and feeder cables. These are the local and connector streets.

The switching centers are then interconnected in a complex of local, intercity, and interstate trunk transmission links. These are carefully organized to provide the necessary flexibility and redundancy for the system and to take maximum advantage of economies of scale that result from bundling together large blocks of traffic.

The analogy need not be belabored any further, for it is evident that, for any class of street or highway one can name, its counterpart in the Bell System network can be identified.

Local telephone transmission is over pairs of wire carefully bundled together into cables of various sizes up to a few thousand pairs. Coaxial cable is used for long-distance, high-capacity systems. Coaxial cable was invented at Bell Laboratories in the 1930s. The first commercial installation was made just before the war, in 1938. We now have a network of 20,000 miles of buried coaxial cable that, together with the microwave radio system, carry the bulk of our long-distance traffic. The first coaxial cable system could carry about 500 voice channels; today it can carry 100,000. The implementation of these higher and higher capacity coaxial and microwave radio systems has been carefully planned to keep pace with the growth in communication traffic demand. Present-generation systems will accommodate the demand through the end of this present decade.

CONTINUING TECHNOLOGICAL DEVELOPMENTS

About 1980, the new millimeter waveguide system will be phased in as the next stage beyond coaxial cable in the continuing exploitation of new technology. In view of the importance of waveguide in future long-haul transmission plans, a brief description of this new communication medium is appropriate.

The initial waveguide transmission system will have a capacity of almost ¼ million 2-way voice circuits, several times the capacity of the largest coaxial cable transmission system. It will be used on the backbone long-haul routes.

The waveguide itself is a highly precise steel pipe with various special linings. It is a little more than 2 in. in diameter and has a wall thickness of a little more than ⅛ in. The waveguide is supported by an elastic suspension system and inserted in the field inside a second steel pipe about 5½ in. in diameter buried 4 ft underground. The manufactured lengths of both waveguide and sheath will be joined in the field by precision automatic welding. Thus the completed structure will be extremely rugged and highly resistant to mechanical injury. Corrosion protection will be provided for the sheath, and a dry nitrogen atmosphere will be maintained inside both waveguide and sheath.

In operation, electromagnetic waves are propagated through the waveguide. In most conventional transmission lines, the transmission loss increases as the frequency increases, but in waveguide the opposite is true. To take advantage of this, we are using frequencies in the extremely high frequency (EHF) range, from 40 to 110 GHz (1 GHz is 1 billion cycles per second). At these frequencies the wavelength is just a few millimeters. This gives rise to the term "millimeter waveguide" which is sometimes used to describe the system.

The bandwidth is enormous—70 GHz—which accounts for the large capacity of the

system. At these frequencies the attenuation or transmission loss of the system is very low indeed. This permits repeater spacing at intervals of about 25 miles. This compares to repeater spacing of 1 mile on the highest capacity coaxial system.

Service reliability is particularly crucial in the high-capacity transmission systems because of their importance in the communication network. No effort is spared to minimize service disruption. The coaxial cables are shielded to improve their immunity to lightning. Helicopters among other things are used to patrol the routes where "dig-up" damage is likely. Complex automatic switching capabilities are built into the system to divert traffic when a failure does occur.

Current experience indicates that there will be about 3 service-affecting coaxial cable failures per 1,000 miles per year. Typical causes are lightning, nearby construction work, trenching, and even farmer's fence posts. There is a continuing program to reduce this rate to the bare minimum. Selection of suitable right-of-way is one obvious means.

Engineering estimates of the inherent reliability of the waveguide medium indicate reduced trouble rates by at least an order of magnitude as compared to coaxial cable. The objective is fewer than 0.3 service-affecting failures per 1,000 miles per year, or fewer than 1 failure per year on a transcontinental system. We believe this estimate to be realistic. It is based on extrapolation of the trouble history on coaxial cable as it would relate to the more rugged waveguide. The estimate is consistent with pipeline experience. Test work at our field laboratory confirms that waveguide is difficult to damage, even with the heaviest construction equipment.

RIGHT-OF-WAY PRACTICES

As a result of technological innovation, we have greatly minimized the amount of right-of-way needed to handle the country's communication traffic. Typically the newer, higher capacity systems have been retrofitted on existing routes without major new outside plant construction. About 90 percent of the new long-haul circuit mileage is being added in this manner. Nonetheless, as the country develops and as demand grows and shifts into new regions, we project a continuing need to extend the system on new right-of-way.

In planning for new routes, we try to ensure that our system dovetails with other public and private utility and transportation systems. We recognize the essential need to arrive at a well-conceived master plan for the utility complex as a whole. The public interest demands no less. We simply must find ways to reduce the demand on limited natural resources such as real estate.

The common features of the transportation and communications networks have made possible the extensive sharing of right-of-way from the very beginning. A large fraction of the telephone network is on public right-of-way by virtue of the franchise rights granted by the various jurisdictions. These rights-of-way are shared not only with transportation systems but with other utilities. Some 70 percent of the utility poles used by the Bell System are jointly occupied with power. The same policies are being promoted to share space and trenches in underground installations. The Bell System is cooperating in a number of active programs in the American Right-of-Way Association and the American Public Works Association so that this scarce public right-of-way can be used to the fullest.

A conspicuous exception to the policy of sharing right-of-way has been practiced in the construction of the high-capacity, long-haul buried coaxial cable transmission systems. With but few exceptions these are on private right-of-way obtained by easement. One reason for the use of private right-of-way has to do with national security. Most of the coaxial systems are hardened and have redundant routing to avoid target centers. Another reason has to do with the need for frequent amplifier stations (every mile or so) and requirements for maintenance access. In all, the Bell System has only several hundred miles of coaxial cable installed on the right-of-way of limited-access highways. This has been the exception rather than the rule.

In the future, we expect many of the constraints to change. For one thing, because of the extensive network of hardened cable facilities already installed, the need to con-

tinue the rigid policy of avoidance routing is no longer so compelling. Perhaps more significant than this though is the planned availability of the new millimeter waveguide system. This system is substantially more trouble-free than coaxial cable, has a reduced need for maintenance access, and has increased immunity from interference due to nearby power lines or construction activity. For these reasons, our feeling is that joint occupancy of limited-access highway rights-of-way may be more feasible in the future than in the past. Waveguide will be used to link distant population centers, as does the Interstate Highway System. It should not be surprising that a substantial coincidence of routing is projected.

PROPOSED JOINT-USE FEASIBILITY STUDY

Existing governmental policies recognize in principle the merits of accommodating the highest type of utility facilities (trunkline and transmission facilities) along and within freeway rights-of-way (1, 2). These policies indicate that such joint use would be in the public interest in those situations where the routing is reasonably coincidental and where the particular right-of-way is of adequate width and otherwise suitable to permit the construction, maintenance, and operation of one facility without adversely affecting the other. These policies have been stated in principle, but many questions remain to be answered before either highway or telephone engineers can say with assurance that joint-use is indeed feasible from all standpoints.

We feel these questions must be answered, and we are prepared to support the study work and experiments necessary to get the answers. The Bell System has suggested a joint feasibility study on a particular freeway section, perhaps several hundred miles long, in cooperation with federal and state highway officials. Objectives are to develop a better feeling for the merits and constraints involved from the standpoint of both highway and utility interests. We visualize a small interagency task force that could begin this study in the near future. Only through such an effort can broad policies be properly defined and translated into action in keeping with the public interest.

CONCLUSION

The utility industries are under tremendous pressure to meet ever increasing demands for service and at the same time to become less and less conspicuous in the environment. The Bell System has implemented vigorous policies for construction of out-of-signt plant and other similar programs during the past 15 or 20 years, but more remains to be done. We need to strengthen liaison and joint planning with the other public and private utility groups. The broad question of right-of-way sharing seems particularly pertinent now as we plan for a major new system in the decade ahead.

REFERENCES

1. Accommodation of Utilities. Federal Highway Administration, PPM 30-4.1, Nov. 29, 1972.
2. A Policy on the Accommodation of Utilities on Freeway Rights-of-Way. AASHO, Washington, D.C., Feb. 15, 1969.