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Telecommunications: A comparison of transmission technologies used in distance education

John D. Kerber

University of Northern Iowa

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Telecommunications: A comparison of transmission technologies used in distance education

Abstract

The purpose of this research paper will be the investigation and comparison of transmission medium technology used for telecommunication in distance education.

Telecommunications
A Comparison
of
Transmission Technologies
used in
Distance Education

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John D. Kerber
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Has been approved as meeting the research paper requirement for the Degree of Masters of Arts.

Sharon E. Smaldino

July 30, 1990
Date Approved
Director of Research
Paper

Robert R. Hardman

July 30, 1990
Date Approved
Graduate Faculty Advisor

Robert R. Hardman

July 30, 1990
Date Approved
Graduate Faculty Reader

Roger A. Kueter

August 3, 1990
Date Approved
Head, Department of
Curriculum and Instruction

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Chapter I

Introduction

Some method must be found to solve the problems of the escalating cost of and sophistication of educational needs. Distance education is the answer.

Implementation of distance education is an ever increasing part of today's educational menu. Many regions and states are now or soon will be involved in distance education network construction.

Distance education provides effectiveness, efficiency, overall cost reduction, reaches large numbers of students, provides higher level courses to small schools, increases demonstration classroom sophistication, increases course variety and student-teacher two-way verbal and non-verbal feedback. Thus, the need for practical transmission mediums to handle information necessitaties investigation.

Purpose

The purpose of this research paper will be the investigation and comparison of transmission medium technology used for telecommunication in distance education.

Limitations

Any investigations or conclusion of the attempted question of which transmission medium is appropriate for particular distance education environments requires a narrowing of technology and situational scopes be stipulated.

Situational conditions will only include inter-and intrastate networks, with major emphasis on interstate. This emphasis will permit reduced concern over governmental rules and regulations that hamper or impede full technological utilization.

Technological conditions to be met must be codified to include only two-way video, audio, and digital information transfer. Discussion of specific transmission technology currently in use will be emphasized. Possible future media augmentation will be discussed but will not be included in the final conclusion.

Types of transmission mediums will be limited to fiber-optic cable, coaxial cable, and microwave technologies. These technologies will be compared to the specific categories of information channel capacity, installation complexity, service accessibility, and operational reliability. Due to wide bidding procedure variations, regional cost differences, geographic physical anomalies, and purchase-time variations, no detailed cost or cost comparisons will be attempted.

Due to the complex and pervasive nature of this technology, a literature search would be deemed an appropriate investigative tool. It is only necessary to compilate our knowledge of its use at this time.

The utilization of technological and investigative focusing elements proposed herein will allow several situation-specific conclusions. Since technological knowledge is increasing rapidly, and this is not an engineering research summary, it would behoove the reader to further investigate the newest uses of the transmission mediums to provide a definitive decision of proper transmission medium in the specific distance education situation.

Definitions

Angstrom - Unit of length equal to 1/10,000,000th of a meter

Antenna - A usually metallic device (as a rod or wire) for radiating or receiving radio waves

Bits - Word derived from binary digits. Smallest units of information in a binary system. A bit represents the choice between a Mark or Space (1 or 0) condition.

Distance Education - Implies that the majority of educational communication between (among) teacher and student(s) occurs noncontiguously, between (among) teacher and student(s) for the purpose of facilitating and supporting the educational process.

EHF - Extra high frequency

Electromagnetic waves - Waves which can be propagated by a transmitter and broadcast through the atmosphere. Both radio and light waves are examples.

Geostationary - Of, relating to, or being an artificial satellite that travels above the equator and at the same speed as the earth rotates so that the satellite seems to remain in the same place.

Giga-G- One billion times the number

Hertz - A unit of frequency equal to cycles per second

Laser - Light Amplification by Stimulated Emission of Radiation

Meter - Base unit of metric system. Measure of length roughly equal to 39 inches

Modulation - The process of modulating (varying) a carrier or signal

Nanometer - One billionth of a meter

Optoelectronic - Branch of electronics dealing with electronic devices for emitting, modulating, transmitting, and sensing light

Photons - Small packets of light energy

Quartz - A mineral SiO consisting of a silicone dioxide that occurs in colorless and transparent or colored hexagonal crystals and in crystalline masses that exhibits properties useful in communication

Rare earth elements - Any of a series of metallic elements of which the oxides are classed as rare earths and which include elements with atomic numbers 58 through 71

Semiconductor - A material that has electrons in the conduction level, at room temperature, of its atomic structure

SHF - Super high frequency

Spectrum - A continuous range of frequencies, usually extensive, within which waves have some specific common characteristic

Telecommunications -Electronic communications at a distance

Transition Elements - Any of various metallic elements (as chromium, iron, and nickel) that have valence electrons in two shells instead of only one (being transitional between the more highly electropositive and the less highly electropositive elements)

UHF - Ultra high frequency

Chapter II

Review of Literature

Overview

All communication systems contain three main parts: the transmitter, the information channel, and the receiver. Although our main focus is the information channel, since this is a system we must also have a brief exposure to all parts.

Logic dictates that we must understand the transmission technologies before comparing their qualities. With this in mind, a terminology definitions and basic technology explanation will be offered, followed by descriptions of fiber optic, coaxial and microwave technology and descriptions of their usage.

Communication Technology Basics

To understand the world of telecommunications, it is necessary first to develop a rudimentary knowledge of communications electronics. A communication system must conform to the basic General Information Model proposed by Claude E. Shannon (cited in Murphy,1987). This model consists of a method of information transfer from transmitter (information source) to receiver (information sink). Whether this is human voice, television, or smoke signals, all communication conforms to this model.

To understand the transmission of information in an electronic communication system, knowledge of the electromagnetic spectrum is necessary. This naturally-occurring energy grouping is made up of waves of energy extending from sound through cosmic rays. Each type of electromagnetic energy has an identifiable wave pattern varying slightly from wave types before and after it on the continuum. As we move from sound waves to cosmic rays, the waves decrease in cycle length.

With this is mind, sound waves would have a long wavelength compared to light waves, and light waves would have a longer wavelength than cosmic rays. If we narrow our look at the spectrum, we see red light having a longer wavelength than blue light, ad infinitum.

Wavelengths are stated in quantities of the metric measurement called the meter. A wavelength is the distance, in meters, that one full wave occupies. One sound could have a wavelength in the range of 3 x 10 meters, a particular radio wave 30 meters long, and so on along the spectrum.

Frequency of these waves would be a comparison of number of full waves per second. One sound, then, would have a frequency of 18,000 cycles per second, or termed Hertz per second (Hz) 18,000 Hz. A radio wave could be 10,000,000 Hz, or 10,000,000 cycles per second. Light wavelengths and above are given special notation due to the high wave frequency. The terms angstroms or nonometer (nm) are used. If we look at a group of frequencies, at one spot on the spectrum, that group is called a band. This band has a particular frequency width, producing the term bandwidth.

These concepts can now be put to use to explain the process of digital and analog modulation (Palais, 1984). In a communication system, there must be a way to use the various types of electromagnetic energy to carry information.

The human voice is a good example of analog modulation. By passing air form the lungs across the vibrating human vocal cords, sound energy of multiple wavelengths (frequencies) are created. The surrounding air carries the sound vibrations to the ear of the receiver. By previous convention, the receiver deciphers the word meanings. Analog modulation consists of continuous faithful reproduction of the original message waveform.

Digital, on the other hand, consists of only two states or bits. One state is on. The other state is off. Expressed mathematically, the "on" state equals the number one, and the "off" state equals zero. The rate of on's and off's per second is called the data rate. It is expressed as number of bits per second, or bps.

Ultimately, digital offers many attractive possibilities for communication systems, from interference protection and conservation of spectrum usage, to simplicity in information transmission and reception. Most current and future communication systems will use digital technology in some form.

Fiber Optic Technology

General Description

Light energy and glass are the prime components of fiber optic communication. More technically "Optical communication is simply the attempt to use light and the photons that constitute light to transmit messages" (Chaffee,1988 p.1). To fulfill this requirement, usable light has to be generated and controlled to produce usable information transfer.

The first practical generator was invented by Bell Telephone Laboratories in 1960. The L.A.S.E.R. produced linear compacted coherent light of a very limited wavelength. This light source could be modulated in digital or analog fashion. Since the receiver element of our communication system already existed, initial communication attempts were made through the atmosphere.

It became quickly apparent that, due to dust clouds, ground heat, moisture, and physical impediments, a solid controllable transmission medium was necessary (Chaffee, 1988).

The most obvious transmission medium material was glass. Fortunately, this glass fiber transmission technology was also being independently researched. Initially, the glass fibers had great light attenuation problems. In 1970 this problem was resolved (Palais, 1984).

Also in 1970, a major breakthrough in receiver technology occurred. Early receivers that converted the light information back to electrical signals, then to human-decipherable information, required large quantities of light. The previously mentioned L.A.S.E.R. transmitter also required great expenditure of energy.

Enter the semiconductor optoelectronic devices. A new energy-efficient transmitter, the light-emitting diode, or LED, and its receiver companion, the photodiode, were discovered by Bell Telephone scientists (Senior, 1985).

Both optoelectronic semiconductor devices rely on a simple physical principle. There are naturally-occurring materials that can be altered to produce electron-deficient or electron-abundant substances. When these substances are placed in contact with each other, and small voltage is applied, electrons flow from the electron-rich N-type material to the electron-deficient P-type material, producing a large current flow. This is called forward biasing a P-N junction (Shrader, 1975).

In the L.E.D., these substances can be modified to produce light in controllable wavelength-specific configurations. The reverse is true of the photodiode. Upon application of light energy, a forward-biased N-P junction will generate a light-regulated electric current (Shrader, 1975).

Coupling these semiconductor devices with glass fiber cable produces an efficient communication system to handle information transfer (Gowar,1984).

Transmission Systems

Thus, a fiber optic communication system incorporates an electronic device that converts video, audio, or digital information into electrical signals. These signals modulate the light output of the optoelectronic transmitter. The modulated light then travels down the glass fiber cable. At the receiver end, the light is detected by the optoelectronic receiver, and the process is reversed, producing human-usable information (Palais,1984).

This system has some limiting factors. The most significant is light attenuation loss in the transmission medium. Another is the interfacing or splicing of the glass fiber ends with electronic equipment, cables, or other transmission technologies.

The light attenuation problem is affected by several factors--cable fiber composition, cable design, and wavelength of light.

It has been determined that the cable fiber made of silica, a quartz compound, lightly doped, is currently best. The doping, or adding of impurities, consisting of transition or rare-earth elements, produces a less light-absorbent glass fiber (Miller, 1988).

Splicing fiber cables must be precisely done. If the spliced ends are not perfectly parallel, the light passed through will be altered, causing a variety of problems. Fusing fiber ends has been the most reliable, but difficult, method. Also, matching technologies with different transmission principles has been a drawback (Koscinski,1987).

The problems have been recently addressed by manufacturers. There are several companies now producing electronics to match coaxial and fiberoptic technologies. Also, more easily installed connectors for fiber optic splices are now replacing the fusing method (Large,1989; Nelson,1988).

The cable construction or design has fallen into two categories--single or multi-mode fibers, (Miller, 1988). This discussion will focus on single mode fibers. These fibers produce a lower light attenuation and consequently are of more value in long-distance communication. Additional benefits are greater bandwidth, ergo more capability for carrying 6 MegaHertz television video, and, currently have easier physical splicing properties, hence less necessity for highly-trained personnel (Stevens,1987).

One factor that has not been totally corrected in single mode fiber is light wavelength transmission effects. Several factors affect this problem--wavelength bandwidth, polarization shift, wavelength frequency, and information data rate (Miller, 1988). Detailing on these factors goes beyond the scope of this paper, but some conclusions have been reached (Chaffee, 1988). The currently-used standard for data-only fiber transmission is single-mode, with 405 mbps (megabits per second), using a light wavelength of 1300 nm. For the larger bandwidth video signal, single-mode fiber, with a data rate of 140 mbps and wavelengths of 1300 nm and 1500 nm are used. Both of these have required the use of the more recently available more highly efficient semiconductor L.A.S.E.R. rather than L.E.D.'s (Large,1989).

Although many other problems are important considerations in fiber optic usage, these fall into the realm of engineering treatises. When integrated into the telecommunications distant-learning environment, it is necessary to only worry about what is necessary to transmit, how far, the technical sophistication of the maintenance, and the ability to interface with existing technology. These topics have been and will be addressed as a comparison with other transmission technologies in the summary section.

Microwave Technologies

General Description

Microwave technology is the oldest of the communication technologies to be discussed. Before the year 1900, Heinrich Hertz was experimenting with microwave frequencies from 60 to 500MHz (Cook, 1986). World War II accelerated the research into microwave use in the form of advance attack warning and gun control aiming uses. Experimentation during this time progressed through the 75,000 MHz frequency range (Cook,1986).

Today microwaves are used for transmission of terrestrial and satellite telegraphy, telephone, digital, and television. It is also used in cooking, law enforcement, and aviation. It has become a pervasive and useful technology.

To illuminate the study of microwave communication, some background study must be pursued.

Three bands make up the microwave frequency assignments--UHF 300 MHz to 3GHz, SHF 3 to 30 GHz, and EHF 30-300GHz. An alternative notation of frequency range is the use of band designators, such as C band, which equals 4 - 8 GHz, Ku, which equals 12-18 GHz (Ha, 1986). The frequency ranges commonly used by distance education are 2, 4, and 12 GHz, with 2 GHz being most used (Cook,1986).

In land to land, terrestrial transmission, microwaves behave similarly to other forms of electromagnetic energy. As with other wavelengths, they can be radiated from an antenna, pass through the atmosphere, and are received by another antenna. Here the similarity ends.

Microwaves, especially as their frequencies increase, are more profoundly affected by the earth they pass over and the atmosphere they pass through (Cook, 1986). The normal propagation pattern of these waves is line-of-sight, but air temperature, moisture, and even air pressure affects this propagation.

Transmission Systems

In a typical terrestrial microwave installation, antenna height and transmitter power are primary design concerns. The sensitivity of the receiver is of minor concern, for if the received signal is of sufficient strength above atmosphere electromagnetic noise, no problems will be apparent.

For satellite microwave, a different set of conditions occur. The uplink, ground to satellite, and the downlink, satellite to ground, antenna sizes are of primary concern. Additionally, the transmitter power and receiver sensitivity are also of paramount importance (Chiddix,1987).

With these points of concern in mind, there are two systems, terrestrial and satellite microwave systems, that need to be examined.

Satellite Systems. Satellite systems are more complex and necessitate sophisticated equipment. The communication satellite requires very complex installation by rocket launch vehicle into geostationary orbit at 22,000 miles above the earth.

Three system components are necessary--the uplink antenna, the downlink antenna, called earth stations, and the satellite repeater.

Both uplink and downlink antennas are parabolic in shape to focus the transmitter and receive signals. A typical transmitter antenna is ten meters in diameter, weighs several tons, and is not automatically moveable, although smaller, temporary-use portable ones may not fit that description (Binkowski, 1988). The need for this antenna bulk can be seen by an example. Sending a signal to a satellite 22,000 miles above the earth is like trying to hit a bulls-eye 22 miles away with a bow-and-arrow.

Once the signal reaches the satellite repeater, electronics must convert the uplink signal to a new frequency and re-broadcast it to the downlink earth station antennas. A satellite repeater can receive and retransmit on several frequencies. There can be up to 24 transponders or repeaters on one satellite (Murphy,1987). At the downlink site, the signal is received, amplified, and processed. The normal receive antenna ranges in size from two to five meters in diameter with bigger being more reliable (Binkowski, 1988).

The typical communication satellite has several inherent problems--reliability, size, and weight.

The reliability factor is obvious. Due to its location, in geo-stationary orbit, service at this time is impossible. A typical communication satellite has an average service life of eight to ten years (Tully & Johnson, 1989). This factor is a function not of electronic equipment reliability but rather of the amount of fuel that the satellite carries for its position-maintaining rockets. All satellites have slightly changing orbits. This control of movement is necessary to maintain contact with the ground stations (Binkowski, 1988).

Size and weight requirements are imposed by the rocket launch vehicle. As these factors increase, so do the launch vehicle requirements (Rees, 1990).

As satellite communication becomes more financially attractive, more users vie for a limited number of satellites. Typically, satellite financial considerations follow normal patterns of supply and demand. In this case, limited education dollars must compete with unlimited business dollars for satellite use. Since there are physical orbit space limitations the last problem translates into lack of educational dollars equals limited satellite time usage (Tully & Johnson, 1989).

Terrestrial Systems. Terrestrial two-way microwave system used in distance education shares some problems with satellite microwave, since both transit the earth's atmosphere at least once.

Transmitter power and antenna height are the major items of concern. Transmitter power is constrained by microwave electronic technology and government license regulations (Rowe,1988). Thus, transmitter power is relatively fixed and is of no practical concern to distance educators other than a direct correlation of equipment cost vs transmitter power and the number of transmitted channels.

What naturally occurs to propagation between antennas is the next factor in these considerations. The atmosphere does four things to a microwave signal. It attenuates, reflects, bends and polarizes (twists) the signal.

As the microwave signal passes over the earth's surface, it can also be bent, reflected, or polarized, by solid obstructions or water. These can be predicted to some degree, and the system designed to take them into consideration. This type of attenuation can be partially controlled by antenna spacing and height.

Another type of attenuation created by moisture, rain, temperature, and dust cannot be predicted. On occasion, they can even totally block the signal (Cook,1986).

Without an engineering study, very few generalities can be put forward. It is even possible that a particular signal path would not work with any transmitter power, antenna height, or practical antenna spacing. It is necessary, therefore, to have a professional microwave engineering firm evaluate an intended transit route (Cerino,1988). As an aside, it is important to remember that this same atmosphere is penetrated twice by satellite signals. In the summary, further comparisons will be made of these technologies.

Coaxial Cable Technology

General Description

Coaxial cable technology is both an inherent part of other technologies and a system basis on its own. This discussion will center around the use of coaxial cable in a systems environment for two-way information transfer, specifically, video, audio, and closely allied digital information transmission.

Coaxial cable is a convenient way to carry electromagnetic waves from one discreet location to another. Its relative freedom from interference made it a practical, simple way to transfer early radio frequency energy to and from antennas, inside buildings, and internally in electronic environments. Its usage was a primary developmental concept in early microwave research.

Coaxial cable (coax) is a transmission medium. It consists of a center wire surrounded by one or more concentrically woven (braided) shields. These shields run longitudinally at a uniform radius. This construction produces a cable that is relatively immune from outside electromagnetic interference (Shrader, 1975).

There are some drawbacks to this medium. As frequency of energy carried increases, so does attenuation. Secondly, this cable can only carry a certain bandwidth of frequencies, which is determined by design and manufacture. Thirdly, the frequency fall-off is not linear. Lastly, temperature affects both its physical and electrical properties. Even with all these drawbacks, it is still used extensively in transmission system design (Southard,1988).

Transmission System

A system designed to handle two-way video, audio and digital information would consist of coaxial cable with additional amplifiers or repeaters to correct the attenuation, limited bandwidth, non-linear frequency falloff, and temperature related problems (Hahn, 1988). Today this is still the most used system in existence. As recently as April, 1988, companies like Lockheed California elected to build a data-plus-video system using all coax. Coaxial technology will be around for many years into the future, at the very least as a part of other transmission technologies (Kim, 1988).

Technology Summary and Update

Basic information about the three transmission technologies has been examined. General historical data, elementary operating concepts, operational properties, and some interrelations have been discussed.

It is now necessary to pull together this information and add more sophisticated concepts before drawing proper system-use conclusions.

Coaxial cable technology was determined to be convenient to work with, usable in other technologies, and frequency-specific and bandwidth-specific. Signal attenuation was based on distance and frequency and was temperature-sensitive.

Microwave technology was broken into two areas--satellite and terrestrial. Terrestrial microwave was sensitive to atmospheric attenuation especially water, solid-object attenuation, and distance attenuation. Its frequency was limited; it used line-of-sight transmission, and it was sensitive to governmental regulations. Satellite microwave shared all the problems of terrestrial microwave, including short life expectancy, limited number of available satellite transponders, limitations of repair capability, and required two atmosphere transits.

Fiber optic technology, still in its infancy, was somewhat difficult to splice, exhibited polarization shift, had highly sophisticated interface electronics and multi-medium interfacing problems, and had low attenuation and large bandwidth.

To conclude this summary, it is germane to look slightly into the future. Several transmission innovations may revitalize the older transmission mediums and partially cure their drawbacks.

Among these are digitizing analog video, spread spectrum communications, and packet communication. All of these will decrease the large 6 MHz bandwidth of each analog video channel and provide increased channel carrying capacity. New constructions materials and electronics will increase reliability and will decrease service problems (Walker,1988).

Chapter III

Conclusions

In the introduction, it was stipulated that this paper would investigate and compare distance education transmission medium technologies. Two disclaimers were stated. One was that an attempted question resolution as to appropriate medium would be surmised. The term "attempted" was used because of the rapid movement of transmission technology. This led to the second disclaimer, that the reader should investigate the latest technological innovations before making a definitive decision.

With these points in mind, and in an effort to reach some conclusions, it would be good to take a hint from the major players in the telecommunications "game", the telephone companies. The telephone companies have been leaders in telecommunications research and have a profit motive in selecting the best transmission medium. Their choice has been fiberoptic technology. It is wise to keep in mind several factors, however. Telephone companies have extensive monetary backing, an established technological background, a broad base of technical personnel, installation equipment, and expertise (Tully & Johnson, 1989). Distance education institutions would have to buy most of these benefits. In addition to the being the choice of the experts, channel capacity and future technical innovation potential appear to point to fiber as a good selection.

Terrestrial microwave transmission technology appears to be a good second choice. It probably will provide a good source of short-distance (30-mile radius) small system usage over the next ten to fifteen years.

A not-very-distant third choice would be a coaxial system with a 20-mile radius (Tully & Johnson, 1989). Even though it was stipulated that no discussion of costs per system would be attempted, it is important to reference the last choice to cost. Satellite two way communication systems present the highest cost due to the expensive uplink and small amounts of available transponder time (Chiddix,1987).

It should be noted that rental/lease of existing business telecommunication networks, such as cable television and telephone companies, should not be overlooked as a viable monetary alternative.

Finally, in an attempt to provide a simple decision starting point, the nomograph Figure 1 is presented. It contains the three major systems discussed and gives a visual representation of the major qualities of each. For example, if the situational environment is a small group of learning sites, needing high-channel capacity, high reliability, ease of operation and maintenance, the only choice would be fiberoptic. It would be noted that coaxial technology doesn't fit the channel capacity parameter.

Insert Figure 1 about here

This paper has barely scratched the surface of the distance education transmission technology question. The rapidity of technological change is astronomical. Perhaps all the suggested technologies will be eclipsed by some yet-unknown technology.

References

Binkowski, E. S. (1988). Satellite Information Systems. Boston: G.K.Hall & Co.

Cerino, C. (1988, Mar). Multihub distribution systems...for cable television application. CED, pp. 38-42.

Chaffee, C. (1988). The rewiring of america: the fiber-optics revolution. Orlando, FL: Academic Press, Inc.

Chiddix, J. (1987, June). Satellite communications: the new reality. CED, pp. 14-25.

Cook, N. (1986). Microwave principles and systems. Englewood Cliffs, NJ: Prentice-Hall.

Gowar, J. (1984). Optical communication systems. London:Prentice-Hall Intl.

Hahn, A. (1988, June). Rural Cable System Design and Construction. CED, pp. 76-82.

Ha, T. (1986). Digital satellite communications. New York, NY: Macmillan.

Kim, G. (1988, April). Lockheed makes its choice. CED, pp.44-45.

Koscinski, J. (1987). Considerations in transmission of analog FDM signals on fiber optic links. Communications Technology, 4 (3), 94-105.

Large, D. (1989, Jan). The starbus network: fiber optics to the home. CED, pp. 64-73.

Miller, S.E. (1988). Overview and summary of progress. In S.W. Miller & I.P. Kaminow (Ed.), Optical fiber telecommunications II. San Diego, CA: Academic Press.

Murphy, R.J. (1987). Telecommunications network: A technical introduction. Indianapolis, IN: Sams

Nelson, L. (1988, Nov). Fiber optic installation. CED, pp.38-50.

Palais, J. (1984). Fiber optic communications. Englewood Cliffs, NJ: Prentice-Hall

Rees, David W.E. (1990). Satellite communications: The first quarter of service. New York,NY: Wiley

Rowe, John (1988). State and local regulations of microwave communications. Communications Technology, 5 (2), 70-77.

Shrader, R. (1975). Electronic communication. New York,NY:McGraw-Hill.

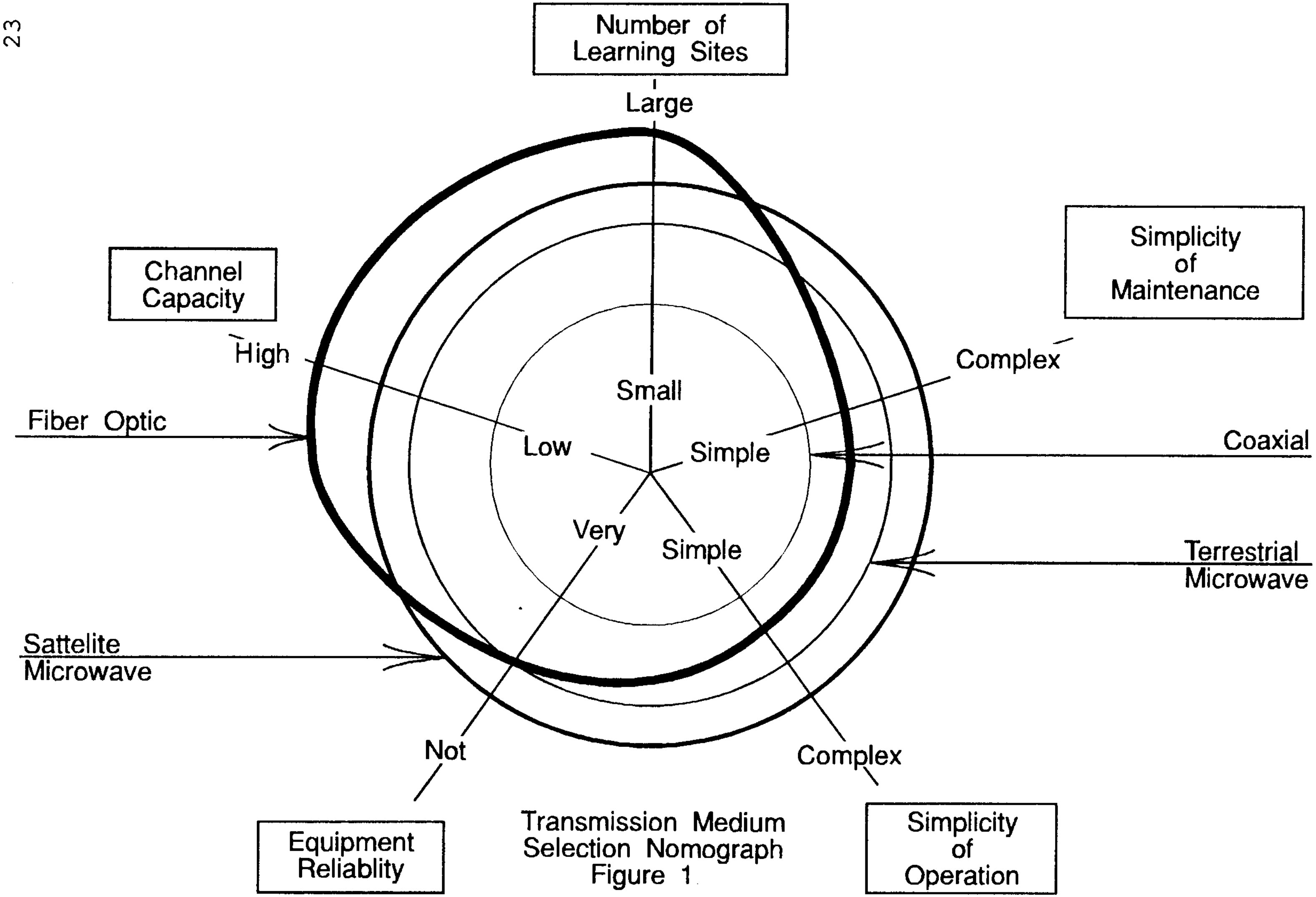
Senior, J. (1985). Optical fiber communications. London:Prentice-Hall Intl.

Southard, R. (1988). Fiber optics in local area networks. Communications Technology, 5 (7), 27-31.

Stevens, R. (1987). Fiber optic cable design and selection. Communications Technology, 4 (2), 38-44.

Tully, S. & Johnson, L. (1989). Interactive television:progress and potential. Bloomington, IN:Phi Delta Kappa.

Walker, R. (1988). System design in fiber-optic video. Communications Technology, 5 (9), 38-40.



Transmission Medium Selection Nomograph
Figure 1