Communications Research Centre

TECHNOLOGY TRENDS IN COMMUNICATIONS

Communications Canada

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TECHNOLOGY TRENDS IN COMMUNICATIONS

CHAPTER 1 INTRODUCTION

MANDATE AND TEAM COMPOSITION

Following the establishment of the CRC as a research institute of the Department of Communications, a committee of senior managers was created to carry out a rationalization of the R&D program at CRC. A sub-committee consisting of two senior representatives from each of the four research branches was established to carry out an assessment and forecast of trends in technology developments in telecommunications and broadcasting.

The mandate and objectives of this sub-committee were to:

- Identify global trends in services, systems and technology
- Identify new areas of work relevant to the DOC mandate
- Prepare a report

To assist in interpreting these, the following terms of reference were provided:

- To address the DOC telecommunications and broadcast but not cultural portfolios
- DOC mandate principally, other clients secondary
- 5-10 year time frame
- Identify but not recommend key R&D areas.

METHODOLOGY

The committee initially adopted a "top down" approach starting with global trends and expanding downwards through services (applications), systems, and finally technologies. This approach proved to be inappropriate beyond the "service" level because systems and technologies apply to more than one service. A "bottom up"

approach was therefore used to identify the technology trends, and their relation to global trends and associated services were then considered.

Chapter 2 summarizes the findings of the top level studies which identified five "Global Trends" in communications as follows:

- Ubiquitous and portable/mobile communications
- Global communications/informatics networking
- Machine-machine communications for control
- Natural human-machine Interfaces
- New broadcast, information and entertainment services

Chapter 3 considers the technology trends. As an organizing principle, a model of communications between people using telecommunications was developed and used and is described in this chapter.

In reviewing these technologies, the committee found that it was necessary to address the social and environmental factors, both regulatory and physical, which will influence the evolution of future telecommunications systems. This review is found in Chapter 4.

The relationship between global trends, technology trends and social and environmental factors helped to highlight key R&D issues and to draw some conclusions. These findings are reported in Chapter 5.

A list of acronyms and abbreviations is included in Appendix I.

CHAPTER 2
GLOBAL TRENDS

The group initially undertook to identify global *service* trends and then, flowing from this, *system* trends. It was later decided to combine these since, although not one-to-one, the overlap in the definitions was considered too strong. Following several meetings, five "Global Trends" in communications were identified and issues or topics appropriate to each listed.

Global Trend #1–Ubiquitous and Portable/Mobile Communications

The global service trend to ubiquitous and portable/mobile communications, intended to provide "access to the individual, wherever he is," is evident in the many activities currently progressing under the broad category of "personal communication services" (PCS) and "personal communication networks" (PCN). One key issue will be the change from identifying the calling/called person's *location* to identifying the calling/called *person* irrespective of location. It is exemplified by various national and international initiatives (e.g., in Canada by Vision 2000) in supporting systems and technologies that are required to offer commercial services. This high level of interest has been motivated to a great degree by the widespread acceptance of and continually-expanding demand for mobile cellular telephone systems.

Demand for wireless portable/mobile communication services appears to be worldwide. Ample evidence for the interest and expected service acceptance is available. Among service offerings that are driving the systems and support technologies required to provide ubiquitous and portable/mobile communications are:

- Wireless public telephone
- Wireless "office" (e.g., ISDN) communication services
- Remote mobile data communication services
- Secure communication services
- Personal security services
- Traveler services (position location, vehicle identification, weather and route information)

Technology issues of special concern for Global Trend #1 are those related to wireless communications, message security, and the necessity to conserve spectrum or open new spectrum for wider band operation. Examples of system and technology developments that are related to this global trend include the flurry of proposals for low earth orbit (LEO) and medium earth orbit (MEO) mobile satellite systems to complement the GEO systems now operating or under development; active research on Ka-band personal communication terminals and related system studies; research and development in cellular and microcellular technologies, including wireless in-building links to users; research related to network integration to support user mobility management; and work in enabling technologies such as mobile antennas and low-power electronics.

Services required to achieve ubiquitous and portable/mobile communications, and the systems necessary to deliver these services to users, are related to all aspects of the communications system model that is presented in Chapter 3, Technology Trends.

Global Trend #2–Global Communications/Informatics Networking

This trend reflects the increasing demand and requirement for "access to information wherever it is". Telecommunications and information networks have become integral to the way business is conducted and with the trend towards globalization of business, global interconnectivity of these networks is becoming increasingly important and essential. At the personal level, there is an increasing use of communications and information networks for activities such as scheduling, banking, purchasing, interactive entertainment, and home/work communications.

The widespread availability of personal computers on virtually every worker's desktop has had a major impact on working methods and is driving the demand for local and global area networks. Over the last decade these desktop computers have been networked primarily in local areas, and over the next decade millions of these local area networks will become interconnected in global networks. An example is the emergence and almost exponential growth of the Internet, a global E-mail and file transfer network serving universities and research organizations around the world. The next decade will likely see the extension of E-mail and other network services to the public through public data networks. Increasingly image, graphics and video applications are also emerging. For instance, the globalization of business is creating a

demand for desktop video-conferencing to reduce travel costs and increase productivity. Other services that are emerging within this trend include:

- Tele-education services
- Distributed computing
- Telecommuting
- Gigabyte distributed database services
- Global entertainment distribution
- Automated integrated business and professional services
- Private business networks (secure)

Technologies of importance in the provision of these new network services include intelligent network architectures, protocols, standards, neural networks, and security/privacy. Global seamless network interconnectivity will also depend on wired and wireless transmission technologies such as cellular and microcellular radio, broadcast systems, satellite systems, in-building wireless LANs, and optical fibre systems. Increasingly, mobile users with portable computers will expect some of the high-speed global network services that will be available on wired networks, thereby requiring development of high-speed wireless access technologies in the microwave and millimeter wave bands. Other important base technologies include digital signal processing, and computer hardware and software.

Global Trend #3–Machine-Machine Communications for Control

An increasing percentage of the telecommunications traffic is used for the transmission of data, as opposed to voice. In many applications the data communications is between two or more machines that must coordinate their own tasks with those of others in an increasingly complex and integrated world. In other cases, a computer may monitor and control one or more remote machines because local control is either uneconomical or unsafe. Examples of services that fall within this trend include:

- Remote monitoring and control (e.g., SCADA)
- Industrial process control
- Automated control of home environments
- Automatic control of vehicles (e.g., IVHS, air traffic control)
- Remote health care
- Command, control, and communications (C^3) for the military

Developments for some of these services, such as industrial process control and air traffic control, are already well under way. Others, such as IVHS, can be expected to evolve slowly over many decades beginning with fairly simple systems based on providing information to human operators and then becoming increasingly sophisticated until a fully automated environment is achieved. Global Trend #3 enjoys a high degree of synergy with Global Trend #1, since many of the systems introduced to support Global Trend #1 (such as mobile telephone, mobile satellite, and in-building systems) provide an infrastructure for supporting machine-machine communications. In other cases, the access will be provided by a tethered or fixed "wired" link. In these cases, the transmission of data will probably be over optical fibres.

Technologies that are likely to be important here include transmission technologies for mobile, in-building wireless, and optical fibre systems. While not necessarily part of the communication systems, base technologies such as position location techniques, sensor technologies, expert systems and neural networks could be important in determining the rate of evolution for this trend.

Tremendous social pressure based upon economical, environmental and health constraints will result in requirements for efficiency and safety that can only be met by an increasing degree of coordinated automation. Over the next few decades this trend will have a profound effect on the way we live as well as on the telecommunications industry.

Global Trend #4–Natural Human-Machine Interfaces

As the potential increases for services that will provide "access to the individual wherever he is" and "access to information wherever it is", the need for natural human-machine interfaces increases. Users will need to know how to tell the system whom they wish to contact, or what information they wish to access. Sophistication of the user interface must increase by putting much of the intelligence into the terminal or system. The interface must be natural for the user, requiring minimal learning and memory. The terminal must understand the user's needs and react to minimal commands.

An increase in the power of micro-electronics is increasing our ability to create more natural user interfaces. There has been progress in recent years in several trends, especially in software for interaction with computers, which promise to put much of

the intelligence into the devices or systems, leaving the user with little requirement to know what goes on "under the hood". Along with the development of better devices for display and user input, research in these should lead to more natural interfaces.

One of three trends is the creation of natural language interfaces, that is, the user can ask questions in a natural language such as English or French. This avoids the current problem that the user must learn the computer's language or wade through cumbersome menus. While services in natural language are limited at present, the increasing power of computers will probably allow much more sophistication to be built into these systems. Combined with voice input, so that user will speak to the computer, this should make the interface much easier.

Another trend is the creation of intelligent agents, which employ artificial intelligence techniques to help users access communication systems. The agents are modeled on the personal assistant metaphor. Agent and user observe each other at work and learn from each other. They communicate by means of the graphical interface rather than using natural language. Predicted to begin reaching the market next year, their full development will take several more years of research.

A third trend is the design of virtual reality interfaces. In any task which requires viewing and manipulation of representations of physical objects in three dimensional space, this may be the most appropriate interface. For example, one Japanese company is using a virtual reality interface to sell kitchen layouts. This interface is also being used in games and may be popular for entertainment. As computer power increases, many of the limitations of these interfaces, such as poor image resolution, will be resolved, but knowledge of how to design them so that the user is comfortable with the three dimensional environment will then be required.

User interface and base technologies that are driving this trend are:

- more complex digital integrated circuits and "subsystems-on-a-wafer"
- neural networks and wavelet research
- expert systems for pattern recognition and database management
- optical computing
- better direct manipulation interface design
- graphical user interfaces
- computer graphics design

Global Trend #5–New Broadcast, Information and Entertainment Services

Recent years have seen an explosive increase in the number and variety of entertainment and information services that have been offered by broadcast as well as non-broadcast services usually using the same consumer equipment. With the increase in quantity, an increase in quality very often also has occurred. The ready acceptance by the consumer of both quantity and quality are good indicators of user choices and preferences. In addition to quantity and quality, entertainment that provides increasingly larger interaction and participation by the consumer is also becoming very popular. Typical examples for quantity are the increasing channel capacity of cable TV networks and the mushrooming video rental stores. Improved quality is exemplified by compact disks for sound and super-VHS for video. The popularity of video games is a good indication of the demand for interactive entertainment. The provision of several channels by cable television systems dedicated solely to information such as weather, stock markets, real estate, etc. is an increasing trend for providing rapidly changing information in electronic form.

All this evolution is leading to a fragmentation of audience and competition among various players to provide better and specialized services. The largest competitive pressure has been on the traditional broadcasters who have depended mainly on the terrestrial over-the-air spectrum as a distribution channel and, because of the channel's constraints, have fallen back both in terms of quantity and in particular in quality. Furthermore in the case of sound broadcasting the primary audience has shifted from the home to mobile users, for which the system was not technically designed and therefore very often provides unsatisfactory services.

These user demands and competitive pressures will soon result in the introduction of new services such as:

- Advanced television (high definition and 3-dimensional)
- Digital radio broadcasting
- Datacasting
- Interactive entertainment services
- Advanced traveler information services
- Virtual reality entertainment

The introduction of these services will be possible due to advances in large scale integrated circuits and digital signal processing as well as the availability of a variety of new transmission technologies such as satellites and optical fibres. Furthermore the merging of broadcast computer and communications technologies will significantly facilitate the introduction of, in particular, interactive and virtual reality type services

which require significant computing power to provide fast response as well as realistic imagery.

CHAPTER 3
TECHNOLOGY TRENDS

TELECOM SYSTEM MODEL

To permit an orderly and thorough assessment of the key technology trends in telecommunications, a model was developed to describe the communications process from the transmitting user or source of information to the receiving user. The model is pictured in Appendix II. A signal sent from A to B requires all of the technologies in the model. The technologies can be thought of as nested in phases or sections; each is necessary for communications, is linked with and influenced by the others, and is an element or functional division in the larger telecommunication system. The following sections describe the technology trends for each of the functional divisions.

TECHNOLOGIES AT THE USER INTERFACE

Interface technologies exist to display information to the user (display technologies) and to accept input from the user (user technologies). Other related technologies are intended to help the process of communication with computers and with other people via the interface (interaction technologies). The following discusses some leading trends in human-computer systems interface technologies.

Display Technologies

Visual Displays - New technologies for the display of visual information will enable departure from the traditional CRT display, now limited in size and expected to improve only marginally in resolution and range of colour rendition. Flat panel displays are constructed from various technologies such as plasma displays, liquid crystal devices and thick film transistors. Larger monochrome and colour flat panel displays are under development with improved luminance, luminance dynamic range, colour rendition, fewer visible defects, and lower cost. Potentially important are also stereo displays which are realized by presenting a slightly different image to each eye using various techniques. Monocular depth cues such as size constancy,

luminance gradients, perspective, and motion parallax could be explored for their usefulness in creating and maintaining the illusion of depth in normal television displays. "Heads-up displays", which present information on a transparent medium so that the viewer's surroundings are also visible, have found military uses and will become important in civilian applications. Small displays for each eye are also under development for use in information processing environments, stereo applications, and virtual reality systems.

Auditory Displays -Technologies are emerging which create accurate illusions of a three-dimensional acoustic environment using two or more speakers. Both production of recordings and design of speakers will be affected. Also, multichannel sound for transmission by radio and advanced television systems is now being considered in standards groups and will likely form part of advanced audio and video systems within the decade. Speech synthesizers will evolve from single unconnected word utterance capability to equipment that will provide proper inflection and stress in complete sentences. Advances in this area will arise from analysis of sentence syntax and semantics to produce more natural sentence utterances.

User Input Technologies

Manual Inputs - The data glove has emerged for use in video games and in virtual reality systems. More recently, multi-dimensional input devices have been developed which can control multiple aspects of an application, such as to conduct the sound of an orchestra.

Speech Input - Current state-of-the-art devices are limited to ten to twenty non-connected words uttered from a speaker to which the device is trained. With current research effort it is expected that speaker-independent continuous speech recognizing devices with vocabularies of several hundred words will emerge in the foreseeable future. Initially such devices will be limited to specific domains of discourse.

Other Methods Of Input - Movement recording devices that use head and eye-movement and movement of other parts of the body as input are important in virtual reality systems and in the remote control of complex machines. They will eventually be important in manipulating holograms that represent remotely located individuals.

Interaction Technologies

The design of interaction technologies is constrained by limitations in users' cognitive abilities (i.e., learning, memory, information processing). Therefore, the trend is to develop interactive processes that require minimal adaptation by the user.

Intelligent Interaction - User interaction has been hampered by interaction technologies that make the user learn new languages and procedures. Several methods of designing intelligence into the technology are making it more natural for the user to interact with an information source or with other people.

Natural language understanding allows users to question a database in their own language as they would another person. Some researchers have been able to develop limited natural language interfaces to relational databases and to other software systems. Examples using multimedia presentations are emerging. With more computer power, these developments will increase in sophistication.

An exciting prospect is conversation with intelligent machine agents that are specialized to perform tasks so that many of the ugly details remain transparent to the user. Intelligent agents employ artificial intelligence techniques to assist users with computer applications. Some of these promise to learn the user's habits.

Multimedia Interaction - Interactive multimedia technologies, using graphics, text, images and sound, are already possible. New technologies for authoring in multimedia are expected for the non-expert user. The next few years will see many developments in authoring technologies and in multimedia communication systems.

Language Translation - Current research in this area uses syntactic and semantic information to improve understanding of ambiguous words in sentences and to generate a syntactically correct translation. The emphasis appears to be on translation of documents rather than real-time speech translation. However, the latter is recognized as an important problem, and the next decade may see creation of usable speech translation systems in limited domains.

Combined Display And Input Technologies

Virtual Realities - By putting on a pair of eyephones, earphones, and a dataglove, a user may explore and manipulate the illusion of a three dimensional world. Objects in the virtual world are modeled in three dimensions using sophisticated computer

graphics. At present, resolution is low and response time slow. Efficient means of simulating human movement are being sought to reduce the computation required. With the availability of increased computational power, the virtual reality interface may approach the capacity of the human sensory systems.

Interface Technologies For The Handicapped

A number of efforts are underway to develop novel interfaces for people who cannot see or have no motor dexterity. Both the graphical user interface (GUI) as well as the keyboard and command line interface are of limited utility in such cases. To circumvent such obstacles, alternatives such as voluntary control of brain activity are being investigated.

SOURCE SIGNAL PROCESSING

Description

Source coding is the process of digitizing analog information into electrical form and then reducing the data to be transmitted by eliminating redundancy and non-essential information through the process of compression (a process whereby some content is lost) and compaction (a transparent process - no content lost). If required, the information will be protected for privacy or against unauthorized access by the process of encryption. Types of sources to be considered for coding purposes include: speech; sound; still images and video; and others such as text, graphics, OCR, and tactile input. The major effort in research concentrates on the reduction of bit rates in view of the increasing demand for mobile communications (cellular/microcellular radio, personal communications systems and military communications) and higher quality in broadcasting.

Speech

Low Bit Rate Toll Quality Speech - Reduction from the present 16 kb/s to 4.8 kb/s is the longer term goal. To achieve this through waveform coding techniques will require a better understanding and exploitation of the human auditory system characteristics.

Vocoding Techniques for Intelligible Speech - Reduction from 4.8 kb/s to 2.4 kb/s at comparable quality is the goal. In addition to better exploiting the characteristics of the vocal tract, new coding algorithms will be required, perhaps through combining the best features of Code Book Excited LPC and Multiband Excitation Coding techniques. Vocoders at several hundred bits per second are still considered inadequate in quality. In the general area of speech coding one key issue will be how to obtain good quality speech in a noisy environment.

Sound

CD-Quality Sound (stereophonic)- The next goal in sound compression is to reduce the bit rate from 128 kb/s to 64 kb/s per channel. It will require optimization of the human auditory perceptual model and use of composite (two channels together) coding and the application of transform coding techniques.

Multichannel Sound - This will be a requirement in all advanced broadcast systems. The issues are to achieve at least 64 kb/s bit rate/channel using composite coding for all five channels. Determining required quality for each channel and compatibility with stereophonic sound are some of the other issues.

Still Images And Video

Still Images - Compression techniques have reached maturity. Minor improvements will be pursued but the main effort will concentrate on applications. Pattern recognition and image enhancement will remain important research topics to solve many issues in robotics, remote control, vehicle guidance, and other areas.

Video (2D) - Compression research is driven by high quality requirements for entertainment and very low bit rates for mobile and video conference applications. For high quality video the goal is to double the compression ratio from the present value of about 25, while maintaining comparable quality. Coding techniques other than DCT will be explored. As well, the complex issue of motion detection and rendition needs to be studied. Multiresolution coding techniques will be another important issue with significant impact on television and image data bases. The lowest bit rate for video is currently 64 kb/s. Trade-offs between spatial and temporal resolution will be studied to improve the subjectively perceived quality.

Video (3D) - The two possible technologies are holography and stereoscopy. Stereoscopy is the more likely candidate for television purposes. At the source coding

level the issues are composite coding techniques and compatibility with 2D video systems. 3D television is likely to become commercially available beyond five years.

Other (Text, Graphics, OCR, Tactile Input Data)

Text - Coding of text (characters) is well established through the well known ASCII code. Little further research is foreseen in this area.

Graphics - Graphics standards have been established. Effort in this area will concentrate on user friendly interfaces in order to increase the use of graphics in engineering design, manufacturing and business.

Optical Character Recognition (OCR) - For printed and typed text, many OCR systems are now available. Correctly recognizing characters from multifont texts or from fonts with touching characters will continue to be an area of research in order to increase recognition accuracy. The more complex nature of recognition of handwritten text as a means to access a computer may only be achieved for relatively carefully handwritten text and systems trained for a single user in the near term. Use of syntax and semantics will be required.

Tactile Input Data - These are types of input sources originating from, for example, data gloves and other human movements as well as machine sensors. Compression of data will depend on the redundancy and correlation in space and time. Many of them are "new sources" and their nature needs further definition.

Encryption (Security)

Encryption techniques have reached a level of maturity where further developments will be incremental in order to improve security as more and faster processing technology becomes available which could reduce time for breaking codes. Areas of research include hard to break but simpler encryption techniques and new mathematical bases for new encryption algorithms. The next several years will see the application of encryption techniques to meet the requirements of a variety of user applications.

NETWORKING

Introduction

Networking deals with the routing of telecommunications, broadcasting and information services between distributed entities. Such entities include sensors, computer workstations, televisions, telephones, and fixed and mobile communications terminals of any kind. These may be distributed in areas ranging from within a computing system to local areas (office buildings, factories), metropolitan areas and wide areas (national, continental, and intercontinental), and are interconnected using various media including wire, optical fibre, and free-space optical and radio waves.

Network Trends

In the next decade, developments in networking technology will be driven primarily by:

- the demand for increased network capacity and robustness, and improved timeliness of information;
- the requirement for seamless end-to-end network interoperability from anywhere to anywhere;
- the requirement for information security;
- the trend towards integration of voice, data, image and video services; and
- the trend towards convergence of network-based data communications, telecommunications and broadcasting services.

Emerging and potential broadband applications of such networks are video-conferencing, multimedia information retrieval, electronic data interchange, distributed computing, distributed work-environments, network-distributed entertainment services, and interactive visualization.

As a result, existing networks will be made more efficient and new networks with order of magnitude higher speeds than today's networks will be developed, made possible by the rapidly increasing performance and decreasing costs of computer, microelectronic, optical and radio technologies. Even with new video compression technologies, many of the broadband applications mentioned above will require

local-area network speeds of 150 Mb/s or higher, and will employ high-speed technologies such as B-ISDN and ATM. Some gigabit-speed LANs will also emerge for very high bandwidth applications such as distributed climatic modeling and real-time 3D rendering. Wide-area interconnection of these high-speed LANs will in turn require network backbones with gigabit speed capability. Wide-area connections at data rates of 155 Mb/s are currently being established (e.g. Internet in the US). Over the next five years connections at 2.5 Gb/s will be developed, and indeed gigabit speed networks for research and education are in the planning stages (e.g. CANARIE and NREN in Canada and the US respectively).

Network Architecture, Modeling, Management

Networks will become vastly more complex in the future with global interconnection of millions of networks, using several propagation media, carrying varied and integrated applications and providing different services and at multiple data rates. Increased network intelligence will be required to implement and manage such networks. Use of open architectures will be essential, and development of and compliance with international standards will be of paramount importance. Areas requiring R&D are:

- advanced network architectures; these will employ distributed intelligence for effective implementation of features such as self-healing mechanisms, adaptive characteristics for dynamic routing and bandwidth allocation, tracking of mobile users roaming through multiple networks, global directory services, etc.;
- architectures for (a) radio-access networks such as terrestrial and satellite wireless personal communications systems (PCN) and indoor wireless systems; and (b) digital television and radio broadcast networks;
- knowledge-based (expert) systems for network management;
- application of new algorithmic approaches such as neural network techniques and chaos theory to network implementation and management;
- analysis, modeling and simulation techniques.

Advanced network test beds in laboratories and gigabit-speed wide-area research networks like CANARIE and NREN will be important R&D tools.

Interoperability , Routing, Addressing, Protocols

LANs of all types will be required increasingly to connect to each other and to wide area networks. These include radio-access networks such as satellite, micro-cellular and indoor wireless systems to meet the demand for ubiquitous portable/mobile access. Since applications will have varying data-rate requirements and different delay sensitivities, networks will need to support multiple-rate traffic (bandwidth on demand) and provide both connectionless (e.g. data) and virtual-connection (for real-time voice and video) services. Achieving interoperability of these networks will be a major developmental challenge. Protocols will be a critical area of investigation, since current protocol schemes do not scale up to gigabit speeds and do not support combined data, voice and video services. Areas requiring R&D are:

- interoperability of wireless and wireline networks;
- integration of communications, broadcasting and information services onto common networks;
- interoperability of megabit- and gigabit-speed LANs with one another and with gigabit-speed wide area networks;
- protocols: e.g. scalable (to work at range of data rates and over different networks); protocols for integrated video, voice and data; and extension to radio-access networks;
- routing techniques such as source and policy-based routing, etc.;
- flow and congestion control techniques in high-speed networks;
- global addressing schemes, including universal personal numbering and hierarchical directories for PCN;

Network Security

With increasing global interconnection of various open systems networks (both private and public) it will be essential to protect user information and resources. Hence security technologies at the network layer, as well as at the source coding layer (discussed earlier), will become increasingly important. Multi-level network security will be essential in order to provide end-to-end security, protect addressing information and ensure confidentiality and integrity of traffic flow. Although a draft OSI standard for network-layer security protocols has been developed, much work is

required in development of multi-level security models, high-speed protocols, and extension of these to radio-based networks.

TRANSMISSION SIGNAL PROCESSING

Introduction

This section discusses trends and challenges to be faced in technology areas including error correction and detection coding, modulation, multiple access, impairment mitigation (e.g., equalization), and synchronization.

Complexity And Capacity Constraints

There are presently two general classes of transmission systems to consider:

i) Those where simple but effective signal processing techniques are required in order to minimize equipment cost. Examples of this class of transmission include cases involving extremely high data rates such as transmission over optical fibres, and cases requiring ultra-low electrical power consumption such as cordless telephone. For this class, the choice of techniques tends to be driven more by device technology than by advances in signal processing and communications theory. Some technology areas that will be important here are optical and electro-optical devices, low-power digital integrated circuit technology, and efficient power amplifier techniques.

ii) Those where sophisticated signal processing techniques are required in order to maximize the capacity available in the allocated spectrum. Examples of this class of transmission include digital audio broadcast, cellular telephone and mobile satellite communications. Here, future choices will be quite dependent upon advances in communications theory. The multiple access battle between the FDMA/TDMA and the CDMA camps will continue for some time to come with each type of scheme being chosen for a portion of new services.

Some technology areas requiring advances if the full potential of FDMA/TDMA is to be achieved include;

- modulation schemes that are simultaneously bandwidth and power efficient (and hence tolerant of interference) - for example, trellis-coded modulation will likely be chosen for some of the future systems, and
- high-performance synchronization and techniques for mitigating time dispersive propagation that are capable of operating with burst-mode signals in fading environments will be required.

Some technology areas requiring advances if the full potential of CDMA is to be achieved include;

- very powerful low-rate FEC codes ,
- very accurate and fast acting power control techniques, and
- synchronization for burst-mode signals with extremely low signal-to-noise ratio.

Eventually there may be some convergence of the above two classes as technological advances allow sophisticated techniques to be implemented at high speed and with low electrical power consumption. Such convergence cannot be expected for several decades.

Higher Transmission Rates, Higher Quality, And Higher Radio Frequency Bands

A longer term trend is the extension of ISDN (144 kb/s) and B-ISDN (150 Mb/s) using radio links (particularly but not exclusively for in-building applications). Furthermore, optical fibre transmission can provide data transmission capability with BERs better than 1 part in 10^{10}. Users will expect similar quality data with their radio accesses. The result is that higher data rates and better reliability, than is currently provided by most mobile and portable radio links, will be a requirement.

Transmission at higher data rates will impact a number of areas. For example, the difficulties associated with the mitigation of time dispersive propagation increase with the transmission rate. If conventional adaptive equalizers are used, very long equalizers may be required resulting in an impractical number of taps to be adapted.

Alternatives include:

- simplified equalization strategies based upon low-order channel modeling,
- channel sounding and precoding (e.g., Tomlinson-Harashima precoding), and
- the use of many parallel narrowband channels (e.g., OFDM).

Higher data rates per user will necessitate very wide spectrum allocations. This in turn will result in the use of higher microwave and millimeter wave frequency bands and will encourage the development of new radio architectures capable of dealing with such wide bandwidths. Very high-speed digital integrated circuits will be required for the implementation of such architectures.

The impact of the reliability requirement is that very powerful error correction and detection coding (e.g. concatenated codes) will be necessary, along with the application of diversity techniques.

Transmultiplexing In Many Forms

Transmultiplexing/filter-bank techniques are necessary for many future systems and concepts. These include satellite on-board processing, satellite and mobile radio base station technologies, systems using OFDM (e.g., digital radio broadcast) and conversion of many FDMA or CDMA signals to/from a single TDM signal for a satellite backhaul or optical fibre transmission.

THE CHANNEL

Introduction

In the present model of a telecommunications system, the block entitled "the channel" is intended to encompass everything required to interface the channel encoded source information with the transmission medium to be used to deliver this information to its intended destination. Within this framework, the channel includes the following technology areas:

- Propagation
- Antennas

- RF Electronics
- Terrestrial wireless systems
- Satellite systems
- Fibre optic systems

Propagation

Effective utilization of the transmission channel requires characterization of propagation impairments over signal paths between a transmitter and receiver, including unwanted interference paths. Wireless (radio) paths are the most difficult to characterize, but similar wave propagation analysis techniques may be applied to all frequency bands up to infrared and optical.

Key research and technology issues for the next five to ten years in radio propagation are related to emerging broadcast and mobile services (both terrestrial and satellite delivery systems); cellular/microcellular applications, including in-building propagation; continuing progression of telecommunication systems to higher frequencies, such as Ka-band for mobile satellites and 60 GHz for indoor use; small-margin satellite systems such as VSATs and USATs; intersystem interference and EMC/EMI; and frequency allocation and standards. Improved models for estimating channel impairments and techniques for adaptive impairment mitigation are prime requirements for the successful implementation of future systems.

Antennas

Current antenna technology development is being driven both by the migration of services to higher frequency bands and the desire for physically smaller antennas in order to enhance user mobility. Specific areas of technology development over the next five years are likely to include:

- *Flexible performance and adaptive characteristics:* efficient use of spectrum through greater directivity; ability to null unwanted signals for mobile or portable operating scenarios; on spacecraft, steerable, beam array antennas with improved antenna sidelobe performance; phased arrays as well as "intelligent antenna" concepts using signal processing.
- *Smaller, conformal antennas:* improved software to handle complex and somewhat arbitrary shapes, at present not possible.

- *Integration of electronics and antennas:* small, portable, novel low cost structures become realizable; combined circuit/antenna design solutions and software; for millimeter waves, inclusion of antenna elements on semiconductor with the electronics in some cases including digital signal processing or optoelectronic circuitry for pattern control and signal distribution.

RF Electronics

Over the next few years developments in RF electronics will be driven primarily by the requirement to reduce the physical size and power consumption of components and subsystems in order to enhance user mobility. Specific areas of technology development will include:

- Convergence of analog, digital and optoelectronic component technologies and the integration of all three into integrated subsystems "on-a-wafer".
- In the UHF bands, the drive will be to increased functionality in a single fabrication cycle or process in order to achieve cost and size reduction.
- Strong demand for low power consumption to meet the demands of portable battery-operated communicators.
- Demand for higher switching speeds to permit increased digitization of receivers possibly directly at RF.
- Drive for wider wireless bandwidths will require significant improvements in technologies at millimeter wave frequencies.

Terrestrial Wireless Systems

The trend to personal communications and broadcast services to mobile users is stimulating significant developments in cellular, microcellular, in-building, and terrestrial mobile systems. Microcellular applications offer substantial gains in bandwidth and capacity, and can provide services such as vehicle location within cells. Services (e.g., FPLMTS) will become essentially worldwide via integration of terrestrial cellular systems with LEO and GEO mobile satellites. Interconnections among the systems will deliver virtually ubiquitous communications capability.

To exploit the above trends, significantly enhanced capabilities to model the transmission channel and adaptively respond to channel impairments are required. Technology improvements are required in antennas, terminal access and

connectivity, digital signal processing and portable power sources. Complex network problems related to system interconnectivity must be solved.

Terrestrial fixed radio systems have evolved from analog systems to high-capacity digital systems at 6/4-GHz and higher frequencies, despite deficiencies in multipath impairment modeling. Field tests of 512 QAM terrestrial systems are in progress. In the next five to ten years, terrestrial microwave systems will probably be used more in an alternate (backup) role as optical fibre becomes more prevalent. Developments in other frequency bands (e.g., HF) are mainly related to networking and related issues; near-term expansion (e.g., as permitted by the new HF allocations of WARC-92) will be similar to the current applications.

The application of free space optical links for communication has been limited by the impairing effects of the atmosphere. A growing area of application is indoor communication links for movable office networks. These networks are low-cost, have high data throughput, are EMI insensitive, and require no spectrum license. Trends in free space optical links include: higher-power, eye-safe sources; high data rates; multipath survivable network configurations; non-line-of-sight links; and wavelength multiplexing for isolation of close-proximity nodes.

Satellite Systems

Present day communication satellite networks are based on a circuit-switched architecture and a relatively simple bent-pipe repeater. Consequently current VSAT networks are based on a star network topology which necessitates double-hop interconnection of VSAT terminals via a master or hub station. In an effort to increase efficiency and to provide a wider variety of services, future satellite networks will be based on a packet-switched architecture and an advanced payload incorporating on-board processing and switching and multiple beam antenna arrays. These future networks will provide full mesh interconnectivity between even smaller user terminals. Optical and microwave intersatellite links may be used to extend coverage and to improve networking. The development of these future satellite networks will require research into the design and implementation of both analog and digital group demodulators and satellite on-board switching systems. At the network management level the problem of synchronization of the satellite and earth terminals must be studied.

Although most commercial satcom services have traditionally been provided by geostationary satellites, the recent emergence of competing low earth orbit systems to provide a variety of personal, mobile and data relay services on a global basis could very well erode the user base of some existing and planned geostationary systems (e.g. Inmarsat and MSAT). The next few years will see a lot of effort devoted to analysing both the technical and the commercial viability of these new LEO systems in order to determine if they can provide a viable alternative to conventional geostationary satellites.

As a result of the ever increasing spectral congestion in the conventional C and Ku-bands, the future will see increasing interest in the use of the Ka-band for both fixed and mobile satellite applications. The regulatory basis for the development of this new frequency band was laid at WARC-92 with the global allocation of frequency assignments. Over the next five years there will be a lot of R&D required both to understand the characteristics of this new frequency band as well as to develop an industrial base for the new technologies required to exploit the large bandwidths available at Ka-band.

A new technology of potential interest to Canada and certainly to the international community (e.g. ESA, NASDA, NASA) is the use of laser communications for intersatellite links. Such systems could find application in a second or third generation RADARSAT for backhauling data in order to minimize the on-board memory requirements. Other future applications of lasercom could be the interconnection of the geostationary satellites of various global communications service providers such as Intelsat and Inmarsat. There are also a number of military applications such as Space Based Radar and EHF satcom.

As new satellite communications technologies emerge, there is a need to explore new system configurations and service concepts and consequences for user terminal configurations. Consequently there will continue to be a need to develop prototype terminals and to demonstrate new service capabilities to the user community.

Fibre Optic Systems

Optical fibre networks currently consist of interconnected point-to-point fibre optic links with signal regeneration, and switching taking place in the electronic domain. The trend in optical fibre communications technology is to all-optical transmission using soliton propagation, wavelength division multiplexing, passive network

architectures with splitters and optical amplifiers, and optical switching. Conversion between the electronic and optical domains will occur only at the end points. The evolution to the all-optical network requires further research and development on optical networks and components.

Network level research would include the consideration of the technical impact of optical fibre technology on network architectures such that the full capabilities of this technology could be exploited. It will also require the development of the standards and electro-optical components required for interconnection and interoperability with other networks.

Components required to implement all-optical networks include optical amplifiers, splitters and combiners, optical filters (narrowband, tunable), optical isolators, dispersion compensators, soliton sources and switches, and wavelength switches. Enabling technologies and materials needed to fabricate the devices are fibre-based processing technologies, planar optical glass waveguide technology, planar optical glass waveguide technology (ion exchange glass waveguides, high-silica optical waveguides and ion implanted glasses), glass photosensitivity and photolithography technology, nonlinear optical materials, and semiconductor materials.

Non-technical issues affecting the development of all-optical networks are increased demand for bandwidth resulting from the growth in new broadband services, possible shift of TV broadcasting in cities to cable distribution, and removal of regulatory restrictions in the delivery of telephone and video services.

BASE TECHNOLOGIES

Introduction

Certain technologies will affect or limit progress in more than one of the previously identified phases of a telecommunications system. This section recognizes the importance of these and highlights potential advances. The technologies which were identified were categorized as; computers; software; electronics materials, devices, and components.

Computers

Supercomputers will be capable of (peak) performances in the hundred's of gigaflops by 1995/96 and will reach one teraflop before the year 2000. The improvements will be based on:

- novel massively parallel processing (MPP) architectures and corresponding radical operating systems and software developments capable of exploiting MPP architecture;
- progress in chip technology, semiconductor materials, increased single processor speeds, and novel on-chip architectures and memory devices up to the petabyte range based upon developments in molecular electronics, all-optical computing systems, and the use of high temperature superconductor materials .
- for peak supercomputer performance beyond one teraflop, the use of free-space optical communications will become essential to handle the speed and complexity of interconnection.

The developments in MPP will be exploited in workstations and personal computers resulting in significant improvements in processing throughput capabilities. This will demand much faster and more 'intelligent' computer networks and inter-computer telecommunications hardware.

Software

Software tools will be developed to improve efficiency of programming and to facilitate adaptation to new computer architectures. Key areas are languages, architectures, and user interface design.

Languages- The increasing size of software programs is raising the issues of development time and cost as well as the verification of the correctness of the final product. To deal with these issues, Formal Description Languages are being developed that will automatically translate a software specification into executable code. In order to ensure that the software is correct regarding syntax and semantics, validation techniques are being developed. Finally, to ensure that the software does indeed fulfill its intended functions, conformance testing techniques are being

developed. These will form important tools in Computer Assisted Software Engineering (CASE).

Architectures- New software will emerge to take advantage of forms of parallel computing. Multiple CPUs will require software which permits tasks performed by conventional programs to be assigned to several processors to be performed in parallel. Parallel distributed processing (PDP) or neural networks, consisting of large numbers of interconnected and cooperating processing units will use learning algorithms. "Client-server" systems in which components of an information processing task are allocated to physically separated computers will emerge and will require software in which as much of the processing as possible will be done by the client computers and which will hide much of the communication with the server from the applications developer.

User Interface- Graphical user interfaces will evolve to provide the most intuitive means for interacting with computer applications particularly as multi-media systems become more prevalent. Development tools that hide some of the intricacies of using a graphical user interface are starting to appear, and this trend should continue into the next decade. Natural language generation algorithms will allow computer systems to understand commands or queries issued in the user's own language. This will be especially convenient for people with disabilities.

Electronics Materials, Devices, Components

The major trends in this category are largely driven by the desire and need to maximize the complexity of function achievable within a given size and power constraint. Some highlights include:

- Convergence of analog, digital and optoelectronics component technologies and the resultant integration of all three into integrated subsystems "on-a-wafer". This will require increased R&D to find technologies, architectures and design methodologies which maximize the performance achievable in mixed function operations;
- Increased R&D into multilayer "motherboard" techniques to permit subsystem level integration using technologies such as multichip modules and advanced microwave circuit design and packaging;
- R&D will increase on new semiconductor materials such as Indium Phosphide (InP) for higher speeds and optoelectronic functions;

- Explorative R&D into conductive polymers with the promise of lower cost electronics;
- Denser digital ICs (over 1 million gates will be readily accessible). This will come with higher switching speeds (multi Gb/s) and A/D conversion frequencies (up to high GHz sampling frequencies) and will be at least in part due to new devices such as heterostructure bipolar transistors (HBT) and quantum well devices; in the latter part of the decade, "all photonic" systems will offer a further increase in speed.
- Substantial increases in semiconductor memory sizes to the terabyte level will be realized. New storage mediums such as optics as well as emerging molecular polymeric storage devices are being developed. High temperature superconductor thin films are being explored to permit even denser and faster memories and digital ICs to be realized;
- Increasing emphasis on low power consumption circuitry and reduced thermal dissipation achieved through advances in fabrication technology and through use of greater integration of function, both RF and digital to meet the demands of portability;
- Semiconductor micro-machining techniques will permit acoustic functions and pressure and motion sensing devices to be integrated "on-wafer" with other electronic functions;
- The technology of higher frequency EHF devices will mature permitting low cost EHF components and therefore systems to be deployed;
- Low loss electronic circuitry, both microwave and digital interconnection will be realized based on use of high temperature superconducting thin-films ;
- Substantial improvements in batteries with high power per unit weight are being realized and will continue to emerge to meet the demands of portable computers and personal communicators.

CHAPTER 4
SOCIAL AND ENVIRONMENTAL ISSUES

INTRODUCTION

On the one hand, communications technology can create environmental and social problems and opportunities and on the other hand, environmental and social conditions can influence the development of communications technology. This section serves to identify briefly some of the social and environmental issues that are relevant to communications technology research.

PRIVACY AND SECURITY ISSUES

The right to personal privacy is one of the articles in the Canadian Bill of Rights. However, the enforcement of personal privacy rights is becoming increasingly more difficult with the growing use of wireless communications connections. Today, eavesdropping on personal cellular telephone conversations is a common occurrence.

A related issue is the growing use of electronic media for storing personal information. Concern over the vulnerability and security of government data banks has been expressed. With the development of wireless access to computers, the difficulty of ensuring the security of electronic data files is exacerbated.

Electronic media are also used increasingly for sending information to those who have not requested it, spurring complaints of invasion of personal privacy. There is need to develop and apply technology to maintain the individual's right of personal privacy.

A global trend is that the operations of government, industry, financial services and society in general rely increasingly on computer and communications networks to function. These networks can be vulnerable to disruption either through natural disasters or terrorist actions. It is important that communications networks are developed that are survivable.

REGULATORY ISSUES

The application of new technology can be hindered by current communication regulations and policies; the development of new technology can make communications policies obsolete. Currently, there are two issues driven by technology trends that are relevant to communications regulatory policies. One trend is a convergence in the provision of communications services (telephone, video, and data) resulting from the capability of broadband fibre networks to deliver digitally all types of services. The issue is which services should the operators of broadband networks be permitted to provide over their networks. A second trend is the growth in mobile and personal communications which has created a significant increase in demand for the use of frequency bands in the electromagnetic spectrum. The issue here is how best to manage the electromagnetic spectrum to meet the demands on its use.

ENVIRONMENTAL ISSUES

In general communications technology is a relatively benign contributor to environmental pollution and in fact is a technology that can assist in reducing environmental pollution. The one environmental problem that communications equipment contributes to and is affected by is "electromagnetic pollution". The worldwide growth in the use of electrical and electronic equipment is increasing the background levels of electromagnetic fields that are present everywhere in the environment. Spurious electromagnetic fields can interfere with the operation of communications equipment and may be hazardous to the health of the public. The adverse health effects of strong electromagnetic fields are well known and have been an area of concern for workers near high power radio transmitters. On the other hand, the biological hazards of long term exposure to low level electromagnetic fields is a controversial issue that requires much more study. In any case, limits on the field strengths for electromagnetic fields for either biological reasons or electromagnetic interference reasons impacts the design of communication equipment and systems. It will be necessary to demonstrate that communication equipment is compliant with recommended safe exposure levels.

CULTURAL ISSUES

The trend in communications is to global access, i.e. uncontrolled exchange of information and cultural products between Canadians and the peoples of the world. On one hand, Canadian cultural industries will face increased competition and on the other there will be greater opportunities for growth in new businesses as providers of information and cultural products. World wide communications standards and global interconnectivity will be significant facilitators for global delivery of Canadian cultural products.

While global access increases, information received by each person from all sources is also increasing, creating a filtering problem. Many people will feel overloaded with information and will not find what they need or discern the trends that will help them function. New filtering assistance, in the form of software aids or in new institutions, will likely develop.

Television and other image based media are thought to have an effect on the behaviour of some people. Issues such as the increasing trend to violence and the literacy/numeracy problem, are thought to be related to television viewing. Further research on these topics will be demanded by the public.

ECONOMIC ISSUES

It is apparent that Canada has become an information society. More than one-third of Canada's GDP is already based on work in the information industry and this is increasing. We are changing from a commodity based economy to an information economy. Much of our prosperity in future will depend on our ability to use the technology, especially to make new services.

Information technology creates diversity and empowers individuals, rather than large corporations. Governments will be required to help start projects so that individuals can use to make information products and services.

The telecommunications industry is both a commodity and an information based industry, creating products and providing new services. As one of Canada's largest industries, it will play an increasingly important role in future, both in producing products and in providing the means for itself and others to create services.

Canada will need an extensive R&D program to use the technologies in the most effective ways and to build the technologies that people really need in order to make new services.

CHAPTER 5
NEEDED R&D

As stated in the introduction, the mandate of the group did not include making recommendations for R&D activity. However, it was felt the group should attempt to provide a qualitative assessment of the degree of R&D opportunity which exists at each of the phases in the processing of information as defined in Chapter 3 and for each of the Global Trends. The results are presented in Table I. Each rating entry in the Table was agreed to by consensus of the group. However, in arriving at consensus for some of the entries, significant exceptions were voiced. These exceptions and the concerns expressed are noted after the table.

TABLE I. NEEDED RESEARCH AND DEVELOPMENT

Technologies / Global Trends	1. User Interface	2. Source Signal Processing	3. Net-working	4. Trans-mission Signal Processing	5. Channel	6. Base Techno-logies
A. Ubiquitous and Portable/ Mobile Communications	M	H	H	H	H	H
B. Global Communications & Informatics Networking	L	L	H	M	M	H
C. Machine-Machine Communications for Control	L	L	M	M	M	M
D. Natural Human-Machine Interfaces	H	M	L	L	L	H
E. New Broadcast, Information and Entertainment Services	H	H	M	M	M	M

(H)igh: High need for R&D here because major issues need to be resolved to progress on this Global Trend.

(M)edium: Some significant issues need resolution. However, progress in the Global Trend will be reliant on progress in other Global Trend areas.

(L)ow: Progress in this technology area is not key to progress in this Global Trend.

Notes to Table[†] :

A. Ubiquitous and Portable/Mobile Communications

A.1 The User Interface was rated as M in consideration that most of the portable/mobile communication in the near future will involve only speech.

A.2 Source Signal Processing R&D was rated H in consideration of the need for privacy and security as well as the difficulty of achieving low bit-rate good quality video over narrow wireless channels.

B. Global Communications and Informatics Networking

B.1 While it was acknowledged that the User Interface could be complex for a mix of information signals, it was rated L in consideration that the major issue in this trend was interoperability.

B.4 While Transmission Signal Processing is an issue here, it was rated M in consideration that the major issue in this trend was again interoperability.

B.6 Base Technologies were rated H in consideration of the important role that software will have in achieving interoperability.

C. Machine-Machine Communications for Control

C.3 Since it was felt that this trend will not be a major stimulus for Networking, it was rated M although some concern was expressed that, for example, IVHS will raise important R&D issues.

C.4 Transmission Signal Processing was rated M since systems, while unique, would be simple, in particular for industrial applications. Concern was expressed regarding vehicle information systems where the need for integrity would be high in an environment with potentially significant interference since lives could be at stake.

C.5 Channel issues were rated M. However, concerns were voiced that, in the case of control communications between vehicles, there could be important propagation issues.

C.6 Base Technologies were rated M although it was recognized that several RF and digital base technology issues remained.

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† The labels refer to the cells in the table where the letter identifies the Global Trend row and the numeral, the Technology Trend column.

D. Natural Human-Machine Interfaces

D.2 R&D requirements in Source Coding for this global trend were rated M despite the recognition that the user interface would depend on capabilities in this area, in particular in the case of virtual reality systems.

E. New Broadcast/Entertainment Services

E.1 User Interface was rated H since new display technologies in particular are driven by services in this global trend as well as by the emergence of electronic entertainment centres.

E.3 Networking was rated M in recognition that while interactive entertainment services will require powerful networks, they will not be a driving force, but will rely on network techniques developed for other needs.

E.4 Despite strong arguments for a higher rating, Transmission Signal Processing was rated M in recognition that most broadcast services were migrating to cable based delivery. It was, however, recognized that the use of new frequency bands (i.e. EHF) and mobile services do create transmission signal processing issues.

E.6 Base Technologies were rated M despite the recognition of the importance of software and artificial intelligence for services such as virtual reality. There was no agreement whether such services will be driven by consumer requirements or by the requirements for industrial applications.

APPENDIX I – LIST OF ACRONYMS AND ABBREVIATIONS

ATM	Asynchronous Transfer Mode
B-ISDN	Broadband ISDN
BER	Bit Error Rate
CANARIE	Canadian Network for the Advancement of Research, Industry and Education
CASE	Computer Assisted Software Engineering
CDMA	Code Division Multiple Access
CRC	Communications Research Centre
DCT	Discrete Cosine Transform
DOC	Department of Communications
EHF	Extremely High Frequencies
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESA	European Space Agency
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FPLMTS	Future Public Land Mobile Telecommunications Systems
GEO	Geosynchronous Earth Orbit
HBT	Heterostructure Bipolar Transistors
ISDN	Integrated Services Digital Network
IVHS	Intelligent Vehicle Highway System
LAN	Local Area Network
LEO	Low Earth Orbit
LPC	Linear Predictive Coding

MEO	Medium Earth Orbit
MPP	Massively Parallel Processing
NASA	National Aeronautics and Space Administration
NASDA	National Air and Space Development Agency (Japan)
NREN	National Research and Education Network (US)
OCR	Optical Character Recognition
OFDM	Orthogonal Frequency Division Multiplexing
OOP	Object Oriented Programming
OSI	Open Systems Interconnection
PCN	Personal Communications Networks
PCS	Personal Communications Services
PDP	Parallel Distributed Processing
QAM	Quadrature Amplitude Modulation
SCADA	Supervisory Control and Data Acquisition
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
USAT	Ultra Small Aperture Terminals
VSAT	Very Small Aperture Terminals

APPENDIX II

FUNCTIONAL DIVISIONS IN A TELECOMMUNICATIONS SYSTEM/APPLICATION