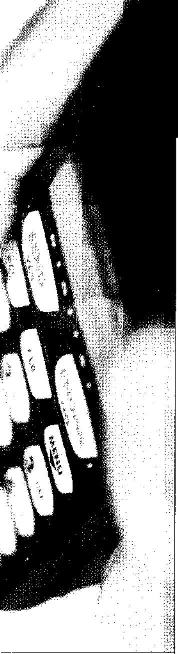

Industry Canada Industrie Canada

TECHNOLOGY

TRENDS IN COMMUNICATIONS

Canada

CRC Communications Research Centre
Centre de recherches sur les communications

Table of Contents

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1.0 Introduction

1.1 *Background*

In 1991, following the establishment of the Communications Research Centre (CRC) as an institute, a committee of senior managers was created to examine the rationalization of the R&D program at CRC. A subcommittee consisting of senior representatives from the two research branches was convened to forecast technology trends in telecommunications and broadcasting. The committee wrote a report in 1992 called "Technology Trends in Communications".

CRC was reorganized in 1997 and its research direction strengthened to reinforce wireless R&D as the principal line of business. In 1998, at the request of the CRC Board, the committee was reconvened. The second edition of Technology Trends was prepared in October 1998.

The committee's objectives were to:

- identify global trends in services, systems and technology;
- identify new research areas relevant to the Industry Canada/CRC mandate; and
- prepare a report on its findings.

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

- concentrate principally on Industry Canada's telecommunications and broadcast portfolio;
- other clients secondarily;
- five-to-ten year time frame; and
- identify, but not recommend key technologies.

1.2 *Methodology*

The committee followed the basic structure of the 1992 report with minor modifications. It was agreed that the "Global Trends" identified in 1992 had continued to evolve, although the titles were modified to reflect an updated appreciation of their significance. One new global trend, *Convergence*, was added to reflect the increasing importance of this trend, which was not adequately addressed under any of the other sections.

Chapter 2 summarizes the six "Global Trends" in communications outlined below.

- Ubiquitous Communications
- Global Communications/Networking
- Machine-Machine Communications
- Natural Human-Machine Interfaces

- Broadcast, Information and Entertainment Services
- Convergence

Chapter 3 considers the technology trends. A model for the way people communicate, introduced in the 1992 report, was again adopted as a methodology for organizing the contents of the report. The methodology is outlined in this chapter and graphically depicted.

In reviewing these technologies, it was considered important 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 the key R&D issues and to draw some conclusions. These findings are reported in Chapter 5.

A list of acronyms and abbreviations used in the report is included in Appendix I and a very brief bibliography is included in Appendix II.

2.0 Global Trends

2.1 *Ubiquitous Communications* Global Trend 1

The global trend to ubiquitous communications, offering access to anyone, anywhere, at anytime, is evident in the many activities currently progressing under the broad category of personal communication services (PCS). One key issue is the shift 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., IMT 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 and interactive data services at increasingly higher data rates and wider bandwidths.

Demand for ubiquitous communications services appears to be world-wide and is being driven by the need to connect terrestrial wireline services to mobile and portable users. Among service offerings that are driving the systems and support technologies required to provide ubiquitous communications are:

- wireless public telephone;
- wireless office communication services;
- remote mobile data communication services;
- secure communication services;
- personal security services;
- mobile information services like position location, vehicle identification, weather and route; and
- wireless multimedia services.

Technology issues of special concern to wireless communications include message security, spectrum conservation and new spectrum allocation for wider bandwidth operation. Technology R&D related to this global trend include:

- optical inter-satellite links to create networks of satellites;
- propagation research and components to support exploitation of the large bandwidths available in the millimetrewave bands;
- cellular and micro-cellular technologies including wireless in-building links to users;
- network integration to support user mobility management;
- transmission techniques that are robust to frequency selectivity;
- enabling technologies such as antennas and low-power electronics; and
- the wired backbone network infrastructure required to support ubiquitous communications services to both fixed and mobile users.

System developments especially important to this global trend include the multitude of satellite constellations, for example, the Iridium, Teledesic and

Spacebridge systems that are at various stages of planning and implementation; development of terrestrial "wireless cable" systems (e.g., LMCS); and other emerging systems intended to enhance user communication capabilities for systems like wireless local loops, high-density fixed systems, and high-altitude space-borne platforms.

Typically, at least in developed countries, only the "last mile" of the transmission is via wireless mode, and the bulk of most message delivery is via the wired network. Consequently, this trend is critically related to *Global Trend #2 - Global Communications/Networking*. As well, development of standards for issues like network interfaces, message identification and control is vital to this trend, thus there is a strong link to *Global Trend #6 - Convergence.*

2.2 *Global Communications/Networking* — Global Trend 2

There is little historical precedent for the swift and dramatic growth of the Internet, which, less than a decade ago, was a limited communication network to facilitate co-operation among scientists and the university research community. Exponential growth of the Internet is being driven by rapid private sector adoption for business communications and marketing. While remaining an important research tool, the Internet has more recently become a "home commodity".

The *Global Communications/Networking* trend reflects the increasing demand, dependency and requirement for access to information wherever and whatever it is. The emerging future global network will provide a powerful and versatile environment for business, education, culture, and entertainment. Sight, sound, and even touch will be integrated through powerful computers, displays, and networks. People will use this environment to work, study, bank, shop, entertain, and visit with each other. Whether at the office, at home, or travelling, the environment and its interface will be largely the same. Security, reliability, and privacy will be built in.

Customers will have the choice of different levels at varying price points. It is intended that this dramatically different environment will provide a more agile economy, improved health care (particularly in rural areas), less stress on the ecosystem, easy access to life-long and distance learning, a greater choice of places to live and work, and more opportunities to participate in the community, the nation, and the world.

Networking R&D focuses on the networking technologies and services needed to stay at the forefront of the information revolution, exploit its benefits and reduce its threats. Key networking research areas include:

- high performance networking (e.g., gigabit networks, optical fibre networks, high-performance wireless networks);
- network management of heterogeneous and large networks;
- technologies to enable information to be disseminated to individuals, multicast to select groups, or broadcast to an entire network (network routing is part of the solution);
- multimedia networking;
- mobile computing/networking;
- analysis, modelling and simulation of networks;
- distributed or collaborative systems;
- high confidence systems to achieve high levels of availability, reliability and restorability of information services;
- high confidence systems to protect against malicious use or unintentional corruption of networking/information systems.

This trend is also tightly coupled to *Global Trend #1 - Ubiquitous Communications*, providing the basic architecture on which networks are built, and *Global Trend #4 - Natural Human-Machine Interfaces*, covering the accessibility and usability of information technology and communications networks.

2.3 *Machine-Machine Communications*

An increasing percentage of 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 co-ordinate their tasks with 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:

- industrial process control;
- automatic control and tracking of vehicles, examples include Intelligent Transportation Systems (ITS) and air traffic control;
- remote health care (e.g., medical telemetry);
- military command, control, and communications;
- automated control of home environments; and
- remote monitoring and control such as Supervisory Control and Data Acquisition (SCADA).

Developments for some of these services, such as industrial process control and air traffic control, are already well under way. Others, such as ITS, are evolving at various rates on a number of fronts. Although some impressive demonstrations have been mounted, the fully automated highway with autonomous vehicle control is at least 20 years away. The reasons for developmental delay are more sociological, economic and political than technical. However, systems less encumbered by these constraints are moving faster. Some good examples are the automatic vehicle location (AVL) and electronic toll collection (ETC) systems that are now being deployed on highways. In another example, emergency vehicles, via a wireless communications link, can pre-empt traffic signal lights to facilitate passage. Such techniques may also be used to enhance the effectiveness of public transit systems.

Systems that collect and filter information from broadcast data and make it available to vehicle operators and passengers are also poised to become a major factor in transportation systems in the next five to ten years. This is an example of a machine-machine communications system that serves as a front-end processor for human users, and may have some capacity to act on its own for such things as weather warning and traffic alerts.

A decade ago, most tele-health projects centred on medical consultation or continuing education needs in remote communities. Today, those combined applications account for only 30 percent of tele-health activity. In the developed world, the most important growth area is the home care market where a range of devices and technologies is replacing some traditional hospital-based services. All require reliable interoperable telecommunications. Examples of service offerings range from tracking the movements of Alzheimer patients, to periodic pacemaker monitoring, to the continuous monitoring of patients vital signs.

Typically, many new machine-machine communications systems, like the automated highway toll collection, involve short-range transmissions that frequently use relatively high bandwidths. Another example destined to become popular in the future is the wireless link between a portable computer and desktop PC that automatically updates information when the two machines are within range of the link. An extension of this concept is the wearable computer. While progress in this field is largely being driven by military applications (e.g., battlefield communications), wearable computers will find their way onto the factory floor, and inevitably, into the consumer marketplace. As homes become more automated, a wearable computer connected via wireless link to the residence will permit remote control of the home environment.

This trend has a high degree of synergy with *Global Trend #1 - Ubiquitous Communications*, since many of the systems under this trend such as mobile telephone, mobile satellite and in-building communications systems are the supporting infrastructure for machine-machine communications.

In other situations, access will be provided by a fixed "wired" link, and data transmission will probably use optical fibre. In either case, the machine-machine communications can piggyback on the link, transparently to other link users. Some novel machine-machine communications applications may be accommodated in cases where a separate infrastructure for them would not be feasible.

Technologies that are likely to be important here include transmission technologies for mobile, in-building wireless (radio and infrared), and optical fibre communication systems. The evolution of solid-state RF device technology to ever-higher frequency capabilities is helping to open up new spectrum for short-range high-bandwidth communications. While not necessarily part of the communication systems, base technologies such as position location techniques, sensor technologies, battery technology, encryption, fault tolerance, expert systems and neural networks could be important in this trend's evolution rate.

As wireless systems continue to proliferate, engineers will have to address increasing concerns about health and safety issues and address the threat of interference between systems. In the past, these issues were not as prevalent because typically systems were situated far from humans and occupied dedicated radio spectrum space. The new generation of machine-machine communications systems must increasingly share spectrum and operate in close proximity to other wireless systems and to the people who use them. This gives rise to concerns about the effects of RF energy sources on the body, and on critical electronic systems (e.g., pacemakers).

The successful development and deployment of these systems will require standardization of the underlying communication protocols, establishing etiquette for spectrum sharing and interoperability between systems. The interoperability issue will be especially critical in mobile applications such as electronic toll collection (ETC) and other electronic payment systems. For example, it would be costly and inconvenient for vehicle owners if toll road operators used different transponders that were not interoperable.

Economic, environmental and safety issues surrounding machine-machine communications will generate tremendous social pressure for a coordinated response to 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.

2.4 *Natural Human-Machine Interfaces* — Global Trend 4

Windows-based functionality and the World Wide Web have conditioned people to expect easy user interfaces to computers and communications systems. The days of memorizing and typing non-intuitive commands at a prompt are long gone. People expect multimedia information to be displayed on screens and to be able to manipulate that information directly with a mouse.

This has created heightened expectation for interfaces that are better-designed and simpler to use. A new generation of non windows-based computer interface technologies are on the horizon that will be improved sufficiently during the next decade including:

- speech recognition and natural language interfaces;
- virtual reality environments;
- intelligent agents;
- information filters; and
- social presence in collaborative environments.

The practical consequence of heightened expectations for more sophisticated user interfaces is a need for much more complex software. Command-line interfaces only require a few lines of code in a computer program. Windows, icons, menus, and pointers require much larger amounts of code. In most modern computer programs, more than half of the code (and often as much as 90 percent) is dedicated to the user interface. Implementing even more sophisticated interface technologies will require vast amounts of code.

However, both of these problems — the demand for new user interfaces that are easier to learn and use, but that require vast amounts of code to implement — have the same solution. Interfaces can be made more user-friendly by adopting a common look and feel so that different programs access the same functions in the same ways. The user is not forced to learn new procedures to accomplish the same functions and does not confuse the procedures of one program with different procedures used in another.

Adopting common user interfaces also relieves programmers of much effort. Even if 90 percent of the code is dedicated to the user interface, they don't need to dedicate the same time to writing interface code because it can be retrieved from pre-written libraries or automatically generated by sophisticated programming tools.

Thus, the dominant global trend in user interfaces during the next decade will be the widespread adoption of a common user interface. Different kinds of communications systems will appear to converge, not just because the underlying technologies are based on a common digital format, but because they have the same appearance to the user. The interfaces most likely to fulfil this niche during the next decade are World Wide Web browsers, such as those already commonly used, but flexible enough to incorporate the new interface technologies.

2.5 *Broadcast, Information and Entertainment Services* — Global Trend 5

The number and variety of entertainment, information and broadcast services offered to the public continues to increase, with a large proportion of these services delivered through the broadcast system. In more recent years, the Internet also has become an important source of information and entertainment, as witnessed by the emergence of Web TV. Consumers also demand entertainment and information suited to individual tastes and needs. This is reflected in the recent proliferation of specialty cable and satellite channels.

It is expected that the trend toward *narrowcasting* — addressing the needs of audience segments with different information and entertainment will continue to increase at the expense of *broadcasting* — providing the same information or entertainment to everybody.

While broadcast service delivery systems already have wide bandwidth to serve the needs of individual users, service providers will look for new delivery mechanisms, particularly wireless, to increase their information and entertainment delivery capacity. With high bandwidth already reaching most users through cable and satellite, this conduit will be exploited to provide new services that are envisioned for the information highway.

Conversion from analog to digital technology signals the beginning of a new era in broadcast services, with digital technology being used both in the creation, and delivery of programs. For broadcasters, it will open up a realm of new possibilities for related non-traditional services. It will hasten the convergence of broadcasting and computers, with the delivery of digital information and services to the home. It will become an extension of the information highway infrastructure and complement the Internet. While for home consumers the television receiver and PC are likely to continue serving different purposes for some time to come, digital broadcasting techniques will permit increasing interchangeability.

Computer games have proven to be highly popular because the user can interact with events on the screen. Interaction is expected to be extended to broadcast services for entertainment purposes, permitting audience participation or consumer response capability when additional information is being sought on a subject that is being televised. Advertisers are also expected to take advantage of interactivity and provide the opportunity to place product orders in an on-line fashion.

Providing information and entertainment in a mobile environment will become increasingly more important. While some countries are already experimenting with television service to vehicles, digital television systems now being introduced in North America have not yet considered this need. Digital audio broadcasting systems are being designed to provide reliable mobile entertainment and information services.

In the future, video is expected to play an even larger role as a transporter of information. Varying usage of video information and display sizes may be satisfied by different spatial and temporal resolutions. Consumer demand for greater flexibility in the creation and display of video, will lead to improvements providing greater freedom for the creators of video information. As well, consumers will be have a broader range of devices capable of accessing video information, and the quality will be scalable to suit the circumstances and budget.

As the technical quality of video and television further improves, demand will increase for greater real life simulation and initial experiments indicate three dimensional (stereoscopic) video and television will provide this enhancement. Today's virtual reality entertainment will become more popular for consumers as powerful processors will provide a very high level of interactivity, improved image quality and realism at affordable cost.

The digital broadcast systems of the near future, while not immediately offering expanded entertainment and information, will provide the platform upon which new services will be developed. Such services will be possible through advances in digital and RF integrated circuit technologies and faster and more powerful processors. Progress in display technologies will lead to flat-panel displays comparable in quality and cost to what is currently available.

2.6 *Convergence* — Global Trend 6

In the past, the range of communications services was quite limited, dominated by commercial radio, television, and voice telephony. These services used incompatible and predominantly analogue transmission techniques. Recently, there has been rapid growth in the variety and the capability of communications services and devices. Coupled with this growth is the expectation that all services will be based upon digital technologies and delivered as data packets. This will allow considerable consolidation in service delivery, communications infrastructure and consumer equipment. Currently many companies, with greatly differing technologies, are competing to capture a fragmented market. While fierce competition is resulting in some excellent opportunities, many consumers and small businesses are uncomfortable with the diversity and complexity of the current situation. This market chaos is driving a set of closely related technology trends that is referred to as "convergence".

Consumers do not want to have many distinct pieces of equipment. Consequently, the complete equipment package will likely be based on a multimedia PC connected to needed peripherals such as a printer/scanner/fax/photocopier device, and audio/visual equipment. Subsets of this package will also be common where portability is important or where restricted functionality is required, for example, a home entertainment unit. The domination of PCs as the core appliance is already becoming apparent, and many telecommunications providers expect that the standard telephone will be gradually supplanted by PC/internet telecommunications. As an interim step in convergence, products such as multi-mode cellular phones and software radios are becoming more common. Setting the pace of this trend are technological advances leading to greater speed, smaller size, lower cost and lower power consumption, for the integrated circuits that form the core of the PC. Similar to the trend identified under *Consumer Entertainment Services*, display, storage and source codec technologies are important.

Users do not want to learn many distinct user interfaces. Consequently, the user interface for many different devices and services will have to be a simpler subset of the dominant Internet interface (e.g., Web browser). A detailed discussion of this is covered in the *Natural Human-Machine Interfaces section.*

Users do not want similar services being provided in a multitude of ways with differing attributes and grades-of-service. To a great extent, the quality of service and the range of services should appear to be the same to the user regardless of where he is or the equipment he is using. Consequently, significant activity is being directed towards the development and implementation of mobile Internet protocols. This trend is also evident in the concepts and practices the ITU is developing for third-generation mobile and satellite mobile systems. The result is that the services available in mobile and portable environments are increasingly becoming an extension of those available to fixed users, with some technical and economic limitations in the quality and range of services. Similar to the trend identified in the section entitled *Ubiquitous Communications*, key technologies include source encoding and compression, transmission techniques for high rate wireless communications, and extensions of network protocols to deal with the greater latency and poorer packet error rates that are inherent in some communications links.

Consumers do not want to deal with a multitude of service vendors. A single point of contact for billing and technical support for the integrated set of services is more convenient and efficient. This trend is sometimes referred to as "bundled services". While on the surface this trend does not appear to have a technical facet, there are major technical implications. Much of the communications systems engineering research will focus on delivering a broad range of services with differing transmission requirements in reliable and efficient ways, taking into account constraints such as limited bandwidth and power. Other challenging issues relate to the interoperability of different — and often competing — transmission facilities.

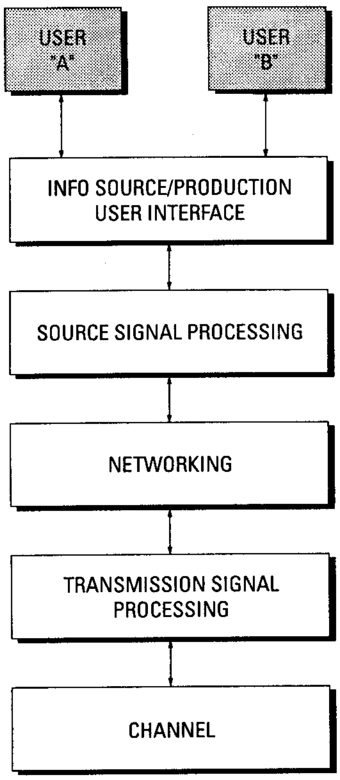
Recent evolution in the regulatory framework has recognized the changes in technology with their potential to enable convergence. It should now be possible to receive any service from any service provider over a variety of delivery media with one and the same device. Despite the technological potential, in practice the path towards convergence is far from smooth, and the practical limit of convergence will not be achieved in the foreseeable future.

3.0 Technology Trends

3.1 Telecommunications System Model

To permit an orderly and thorough assessment of the key technology trends in telecommunications, the model depicted here is used to describe the communications process from the sender to the receiver. A signal sent from A to B requires all of the technologies in the model. Each technology in the transmission process is necessary for communications. It is linked with, and influenced by, the others, and is a functional division in the larger telecommunication system. The following sections describe the technology trends for each of the functional divisions.

FUNCTIONAL DIVISIONS
IN A TELECOMMUNICATIONS SYSTEM/APPLICATION



3.2 *Technologies at the User Interface*

3.2.1 Introduction

The foremost problem created by the explosion of new communications services is the information overload that is constraining the demand for these services. The solution needs to address easier access to information, filtering for unsolicited information and more understandable presentation formats. Advances in user interface technologies will provide the fundamental tools necessary to address this problem, as well as other issues, such as improving access for people who are less computer savvy.

3.2.2 User Interface Tools

Voice Recognition

Considerable research is being directed toward the development of voice recognition because there is a strong perceived demand for voice interfaces. Although voice recognition will find a few applications, it will not likely allow keyboards to be replaced by microphones due to the grammatical differences between spoken and written language. Nevertheless, computers that transcribe speech will be developed in the next few years. People who suffer from hand and wrist repetitive strain injuries may not find relief, however, since voice-activated systems put strain on the larynx. The most important practical applications for voice recognition will arise from the use of telephones as computer terminals for applications such as intelligent voice menu systems.

During the next decade, the user will still have to respond directly to prompts because voice recognition technologies will not support sufficiently large vocabularies in combination with speaker independence to allow voice menu systems to recognize unanticipated speech. Improved telephone shopping systems will be developed in which the customer is asked to speak the names of products from published or broadcast catalogues. Voice recognition may be used to access traffic information systems in vehicles through digital radio broadcasting or wireless network connections, only if ways can be found to ensure that the driver's voice interactions do not interfere with the safe operation of the vehicle.

Natural Language Interfaces

Interfaces that accept questions or commands in vernacular languages will continue to be in demand. Natural language interfaces, using labour-intensive methods, can be manually constructed by creating a rule for each sentence that is likely to be encountered. True natural language understanding, the approach that is taken by computational linguists and artificial intelligence researchers, is still confounded by difficult theoretical problems. During the next five years, consumer applications, such as online help systems for popular computer programs, will use manual authoring techniques with their inherent high costs. In the longer term, both voice recognition and natural language recognition will become sufficiently mature to have a massive impact.

Virtual Reality Interfaces

Virtual reality (VR) interfaces provide ways for people to interact with three-dimensional models stored in computers. To allow the user to visualize the third dimension, the user must be able either to move the model in front of a stationary viewpoint or to move the viewpoint around a stationary model. These visual displays will be combined with three-dimensional audio systems that localize the source of sounds emanating from the models. As well, haptic interfaces, such as force-feedback gloves and joysticks, will allow tactile interaction with VR models. Virtual reality interfaces have not only become a standard feature for computer games, but are fundamental to computer-aided design and are becoming more common for the visualization of scientific and economic data sets. The Virtual Reality Modelling Language (VRML) provides an open standard for encoding VR models. With the development of the VRML standard, the incorporation of VRML viewers into WWW browsers, and the availability of tools to create VRML models, virtual reality will be exploited as a new tool for designing user interfaces, especially interfaces for managing large amounts of information. Because interesting and useful VR models require large data sets, virtual reality interfaces and services will drive the demand for substantial increases in network bandwidth capacity.

3.2.3 Information Management Technologies

Information Retrieval

Retrieving information by searching full texts for specific words does not work very well because most words have multiple meanings and a variety of synonyms. More sophisticated approaches require the computer to be able to read and understand documents. This may be done by calculating statistical measures of word frequency or by using natural language understanding. Effective statistical algorithms will require at least another five years of development and natural language understanding more than two decades. In the immediate future, the best indexes will be designed by knowledgeable people rather than automatically generated by computer programs. Thus, the most important advances in information retrieval research over the next few years will be the development of tools to assist computer-savvy librarians and subject experts to create and maintain virtual libraries.

Information Filtering

Filtering out inappropriate information can enhance the results of information searches. Information filtering is especially crucial for e-mail because "spams" — mass mailing containing advertisements — can overshadow important messages. As fast as programs are developed to filter out the spam, spammers adjust to trick the filters. Ever more sophisticated ways to sort information based on its content are emerging from this ongoing contest. The development of sophisticated information categorization algorithms will be applied to the results of WWW search engines. Filtered search results will not be as good as the results from using human-created indexes, but will be a vast improvement over the current search engines.

Information Visualization

Current information systems lack the ability to display a large amount of information concisely and meaningfully. To date, excellent technologies for displaying numbers have been devised, including descriptive statistics, graphs, and charts. During the next few years, research is needed to develop analogous technologies for displaying concepts. Some primitive attempts to do this, such as semantic networks and cognitive mapping, have had only limited success because they rely on single words or short phrases to label whole concepts. Better ways to visualize a conceptual space will require a fundamental breakthrough in cognitive psychology. We need to know how the human brain acquires and encodes high-level concepts in order to represent them in user interfaces.

Information Authoring

Adoption of the WWW has occurred quickly because the creation of information is easy. People want to present information more effectively and the current way of writing dynamic documents is to use JavaScript and Java aplets. People who must devote considerable time and effort to writing text cannot afford to spend additional time learning the exacting art of computer programming. They will need tools that allow them to create dynamic documents without having to acquire extensive additional knowledge. Considerable research on WYSIWYG programming environments, intelligent programming assistants, and program construction kits is required.

Agents, Bots and Avatars

Agents and bots are computer programs that work in cyberspace without human supervision. Each will perform a specific function that is feasible for an entity with limited intelligence. Mobile agents and bots travel from node to node around the Internet searching for specific information, deleting inappropriate information, or correcting erroneous or outdated hypertext links. Static agents remain on a single computer and retrieve information or act as traffic cops to provide directions to people and mobile agents who are navigating the WWW.

As agents and bots become more powerful, they will pose a threat to the integrity of the information in cyberspace. This will drive demand for secure networks in which the source of every agent and bot is identified, cannot be spoofed, and cannot be repudiated. Specialized kinds of bots called avatars will live in virtual realities. The word, "avatar," from the Hindu word for a representation of a god in the real world, designates a representation of a human being in a virtual world. Avatars will have to engage in a wide range of human-like behaviours, which will require that they be at least as intelligent as a bot. As there is no limit to the sophistication that will be demanded of agents, bots, and avatars, there is no limit to the research that will be required.

Accessibility

The development of new interface technologies will create further challenges for people living with disabilities and opportunities for technological accommodation of their needs. A person living with an impaired sense will be unable to engage some types of user interfaces. However, research can investigate ways to allow the use of an alternative sense to provide information that is required.

3.3 Source Signal Processing

3.3.1 Introduction

Source coding is the process of digitizing analogue information into electrical form and then reducing the data to be transmitted by eliminating redundancy and non-essential information through the processes of loss and lossless compression. Significant strides are being made in expanding the capacity of both wired and wireless transmission systems. Concurrently, the demand for high bandwidth services, such as video, is continuing to significantly increase. Since spectrum is a scarce resource that can only be reused in a limited manner, compression of information sources will remain an important requirement. Types of sources to be considered for coding purposes include speech, sound, video, and other sources such as still images, text, graphics, OCR and tactile inputs.

3.3.2 Speech

Speech compression work will continue to concentrate on lowering the bit rate for toll-quality speech from 8 kb/s — the recently recommended ITU standard — to 4 kb/s, and non toll-quality speech from 2.4 kb/s to at least 1.2 kb/s, and possibly below 1 kb/s at comparable qualities. In order to achieve these goals, better models of the vocal tract and hearing tract are required. Such models will likely be developed within the next few years. Low bit rate speech research is primarily driven by wireless military communications and civilian PCS systems.

Almost all speech processing work assumes a maximum speech bandwidth of 4 kHz (typically 3.2 to 3.5 kHz). There are, however, applications where a higher fidelity is required. The goal of the research on 8 kHz bandwidth speech compression is to achieve the same bit rates that have been achieved for regular speech bandwidth.

3.3.3 Sound

Sound signal processing will continue to develop advanced compression algorithms that take advantage of perceptual models in order to reduce bit rates. There are two objectives for this work: to achieve high quality sound at lower bit rates than currently possible; and to achieve low bit rates for multimedia applications where sound quality need not be high.

Low bit rate compression algorithms to achieve high quality sound are required for radio broadcasting and music listening. Currently within the MPEG-2 family of standards, transparent sound quality at 64 kb/s per channel has been achieved with the Advanced Audio Coding (AAC) method. The future objective is to reduce bit rates to between 32 to 56 kb/s per channel.

The current primary sound source is based on the CD standard which uses a 44.1 kHz sampling rate, and 16 bits per sample is now considered inadequate. A new standard is emerging which will use a 96 kHz sampling rate with 20-24 bits per sample. This standard is already being used for some professional digital audio tape (DAT) equipment. It is expected that various quality audio bit streams will be derived from this primary source and will be offered on digital video disk (DVD) equipment to consumers. Future replay equipment is expected to have multi-standard decoding, capable of decoding variable sound quality at different bit rate standards. Such a capability will be a step towards providing scalability, which is considered a requirement for multimedia applications.

Very low bit rate compression research, guided by ISO/MPEG-4, will extensively use perceptual models and coding by synthesis techniques. It is expected that the knowledge base of perceptual models will be re-examined since the original research dates from the 1930s and 1940s.

3.3.4 Video

Research in the last decade produced the now widely used MPEG-2 compression standard for video. It was developed primarily for good quality video that would be required for various multimedia and broadcast applications. It is based on the Discrete Cosine Transform (DCT) algorithm. No further coding efficiencies are expected using the DCT technique, due to the maturity of this technology.

In the near term, research will be conducted to achieve practical stereoscopic video coding techniques compatible with emerging digital video technology that can be implemented relatively inexpensively, particularly in a broadcast production environment. Issues that require further investigation include viewer perception and the development of a simple and efficient encoding method to convey information disparity between the left and right images.

In the longer term, video coding and compression research aims to satisfy various application demands including better image quality for a given bit-rate, scalability and the ability to derive different image qualities from a given image bit stream that will suit the user equipment or the application at hand. Scalability will go much beyond the capability that some of the MPEG-2 profiles provide, as well as offering a minimum quality penalty for a given bit rate.

Under the ISO/IEC MPEG-7 project, which is developing an object-based description language, the desire is to access image sequences using object-based techniques. Another requirement is to develop multi-format coding techniques that may permit sequences to be viewed in varying formats (i.e. SDTV, HDTV, etc.) to suit different applications. Adapting the coded bit stream to different bit rates, for example, to meet varying transmission media capacities or to cope with network congestion problems, is yet another need. Transcoding is a promising technique that permits this coding transformation to be accomplished without fully decoding the original bit stream, and it has the advantage of minimal loss in quality. These techniques provide for greater flexibility in applications that can accommodate transmission media with varying bit-rate capacities. It is expected that object-based coding techniques will be able to meet many of these demands while providing higher coding efficiencies compared to DCT-based techniques. Research is also being carried out to achieve joint extraction of video features, such as objects, motion and texture that would further improve coding efficiency. Much of this research is being carried out under the umbrella of MPEG-4. Practical implementation can be expected within the next five years, although progress is partially dependent on future processor capabilities to implement such complex algorithms in real time.

The longer-term goal is to achieve much more open coding and compression architectures that would permit the reception and decoding of a variety of compression schemes with a single receiver. Such flexibility will require the efficient downloading of the coding algorithm to the decoder, together with the video bit stream. The concept of Perceptual Coding, which has been successfully applied to speech and sound coding to significantly reduce bit rates, is also being considered for video coding. However, due to the much more complex nature of video information compared to sound, progress is expected to be relatively slow.

3.3.5 Other Sources (Still Images, Text, Graphics, OCR, Tactile Input Data)

Coding and compression technologies for text, still images and Optical Character Recognition (OCR) are relatively mature and widely accepted standards exist. Research will continue to expand OCR technology to hand-written texts.

Graphics

Several graphics standards exist and recent effort has been directed toward making these standards computer platform-independent. Also, in recent years significant development has occurred on the so-called 3D graphics techniques. While the representation of such graphics images is still two-dimensional, the information inherent in the graphics permits display of the same object from different viewing angles. Significant use of this technology is being made in industrial design as well as in computer games, and it is expected to find other business applications in the coming years. Further developments in this technology will be enhanced by efforts to improve existing interfaces and make them more user-friendly.

Tactile Input Data

Input sources, such as data gloves, for example, will convey instructions for human movements for the manipulation of tools and equipment at remote sites, for tasks in dangerous environments or where there is a human health hazard. Some of this information will also originate from machine sensors. Data compression requirements will depend on the redundancy of the information and correlation in space and time. Many tactile input data sources are new and their nature needs further definition. It is expected that a significant influence will come from the field of "virtual reality" as well as the need to perform operations remotely in outer space.

3.4 *Networking*

3.4.1 Introduction

Networking deals with the integration of communications assets in an interoperable, manageable, and secure environment that supports the delivery of telecommunications, broadcasting and information services, regardless of location or appliance type. These include sensors, computer workstations, televisions, telephones, and fixed and mobile communications terminals of any kind. They may be distributed computing systems ranging from local areas (office buildings, factories) to wide areas (national, continental, and intercontinental). They are interconnected using various media including wire, optical fibre and free-space optical, radio waves and satellites.

3.4.2 Network Trends

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

- demand for substantial increases in network capacity, and improved speed of information delivery;
- requirement for seamless end-to-end network interoperability;
- requirement for information security;
- convergence of network-based data communications, telephony, telecommunications and broadcasting services and the rapid convergence of computing, communications and information technology; and
- the goal of achieving an interactive "infosphere" accessible to all.

Potential distributed broadband applications that are emerging include: computing; work-environments; interactive virtual worlds; network entertainment services and interactive visualization. Applications such as video conferencing, interactive multimedia and electronic data interchange will continue to represent a significant portion of the traffic over the next five years. As a result, existing networks must become more efficient and new networks must become vastly faster, aided by the rapidly increasing performance and decreasing costs of computer, microelectronic, optical and radio technologies.

Many of the broadband applications mentioned will require local-area network speeds of 1 Gb/s or higher and will employ high-speed technologies such as Gigabit Ethernet and ATM. Wide-area interconnection of these LANs will require network backbones with giga-bit and higher speed capability. Wide-area connections at data rates of a few Gb/s or greater are currently being established, for example, the U.S. Internet. Tera-bit speed networks for research and education are in the planning stages, with CANARIE in Canada and NREN in the U.S. Generally overlooked as the driver in network traffic volume is the rapidly growing home computing user, with demand for increasing access speed.

3.4.3 Network Architecture, Modeling, Management

The global interconnection of millions of heterogeneous networks, will make networks vastly more complex in the future. They will use several propagation media, carry varied and integrated mixed-media applications and provide different services at multiple data rates. Increased network intelligence will be required to implement and manage such networks and to compensate for human limitations to fully comprehend the behaviour of such large systems. Use of open architectures will continue to be essential, and development of, and compliance with international standards, will be of paramount importance. Areas requiring R&D include:

- advanced network architectures relying on distributed intelligence for the effective implementation of self-healing mechanisms, adaptive characteristics, intrusion detection, etc;
- architectures for the efficient integration into a "network of networks" of terrestrial wireless and satellite wireless personal communications networks (PCN) and digital television and radio broadcast networks, along with more traditional computer networks;
- distributed intelligent agents, including knowledge-based expert systems for network management;
- application of new algorithmic approaches such as neural network techniques and chaos theory for network implementation and management;
- analysis, modelling and simulation techniques.

Networks have become so complex that new architectures, algorithms and protocols must first be evaluated through semi-analytic models or through modelling and simulation. Advanced, specialized network test beds will be important R&D tools when such models or simulations are not possible, owing to the complexity of the problem or the lack of background technical information.

3.4.4 Interoperability, Mobility, Routing

Individual network technologies are aggregated into a "network of networks" or an information highway composed of widely dissimilar networks ranging from kilobit HF networks to terabit optical networks. Each constituent network is characterized by the Quality of Service (QoS) it can provide. Each application/service imposes a QoS requirement on the underlying network. The challenge of emerging and future networks is to provide integrated, interoperable and secure communications transparently to mobile users.

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/outdoor wireless systems to meet the demand for ubiquitous portable/mobile access. Fixed backbone segments may include a mix of microwave, copper wire and optical networks. Since applications will have varying QoS requirements, networks will need to efficiently support multiple traffic beams, each with its own bandwidth and time sensitivities, while preserving their inherent inter-relationships. Achieving "interoperability" of these networks will be a major challenge. Areas requiring R&D include:

- integration of communications, broadcasting, computing and information services onto common networks;
- protocols to enable information to be disseminated to individuals, multicast to select (dynamic) groups, or broadcast to an entire network (network routing is part of the solution);

- scalable protocols (to work at a range of data rates and over different networks);
- routing techniques such as source and policy-based routing;
- multidimensional/multivariate routing algorithms;
- flow and congestion control techniques in heterogeneous networks;
- QoS and address mapping at the boundary between networks of different types (e.g., wireless/wireline networks); and
- High Confidence Systems (robust) to achieve high levels of availability, reliability and restorability of information services.

3.4.5 Network Security

Numerous media reports have documented the ease of interception of wireless communications and the potential embarrassment that can result. In fact, the same vulnerabilities exist in all communication systems. Security is rapidly becoming a critical aspect of communications systems. Key drivers include:

- most of a nation's critical infrastructures (e.g., economic, health, transportation) depend to some extent on underlying information systems which are based on communication networks;
- the global interconnection of various open systems networks (both private and public) is increasing; and
- the number of users of such open systems is growing rapidly.

While bulk encryption technologies are well understood, end-to-end security technologies at the network layer, as well as the source coding layer, will become increasingly important. A wider range of security services will become necessary such as proof-of-origin, non-repudiation, user authentication, and digital signature, to support emerging applications. Such technologies will be insufficient, and it will become critical to develop new technologies to protect against misuse or sabotage of networking/information systems.

One significant change in recent years, that will have a strong impact on the future in this field, is the fact that security is no longer being viewed as an absolute requirement. Robust security provisions are now being justified by analysis of investment cost, risk of damage, value of loss, operational impact and lifecycle cost.

3.5 *Transmission Signal Processing*

3.5.1 Introduction

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

Transmission systems can be considered in two general classes.

- Systems where simple but effective signal processing techniques are required in order to minimize equipment cost. Included here are cases involving extremely high data rates such as transmission over optical fibres. The choice of techniques tends to be driven by device technologies, with high-performance optical and electro-optical devices being particularly important.
- Systems where sophisticated techniques are used to maximize the capacity or throughput provided by available resources (allocated spectrum or cable bandwidth). Here, future choices will depend on advances in signal processing and communications theory. Also important are advances in low-power digital integrated circuit technology, smart antenna technologies, and power-efficient linear amplification techniques.

For the first class, while rates will be pushed to new limits, fairly conventional transmission techniques will be used. Consequently, the focus of this section will be on the second class of system.

3.5.2 Time Dispersion

As noted in Section 2.1 *Ubiquitous Communications*, there is a trend towards service delivery at increasingly higher data rates. Consequently, there is on-going pressure to increase the throughput capability of many communications links. As the data rate over a given link is pushed toward its limit, time dispersion or frequency selectivity become a serious impairment. For many applications, the complexity and performance of conventional equalization approaches could be unacceptable. Alternative approaches to dealing with time dispersion include:

- simplified equalization strategies based upon low-order channel modelling;
- channel sounding and pre-coding (e.g., Tomlinson-Harashima pre-coding);
- multi-carrier transmission techniques (e.g., OFDM); and
- Rake reception with spread spectrum transmission.

Clever combinations of the above approaches warrant investigation.

3.5.3 Interference

Maximizing the total throughput of a given transmission medium often leads to inter or intra-system interference becoming a dominant impairment. Consequently, research into interference avoidance and mitigation schemes is important. Two important examples of interference mitigation techniques are:

- multi-user detection; and
- adaptive interference cancellation taking advantage of the cyclo-stationary nature of the interference.

CDMA appears to be winning the battle against narrowband TDMA for wireless applications for which co-channel interference from adjacent cells (terrestrial), or beams (satellite), is a dominant impairment. This advantage stems from the fact that the co-channel interference is the average, due to all of the users in the adjacent cells, typically resulting in a lower level and variation in the power of the interference. Virtually all of the proposed third-generation cellular and PCS systems have selected a CDMA multiple-access scheme.

For the outbound case, intra-beam interference is typically minimized by the use of synchronous CDMA. Interference cancellation is useful to improve capacity, by mitigating some of the co-channel interference effects. For the inbound case, asynchronous CDMA is typically chosen, due to the difficulty of accurately synchronizing the signals transmitted by the mobiles. Here, multi-user detection within a group of base stations holds a lot of promise. Interestingly, this trend might lead to the return of narrowband TDMA for the return link in future generation systems (fourth and beyond)! This is due to the fact co-channel transmission is no longer "interference" but a diversity path, and nearly optimal joint detection is more feasible with a small number of co-frequency signals.

3.5.4 Transmission Capacity

In 1993, the introduction of *Turbo* decoding surprised the communications industry by demonstrating performance levels very close to that promised by *Shannon's* channel capacity, using a technologically feasible solution. Central to this advancement is a form of iterative processing that is often referred to as *"Turbo processing"*. Initial work focused on coding and decoding techniques devised for an additive white gaussian noise channel and antipodal signalling (e.g., BPSK or QPSK). More recently, researchers have found ways to apply *Turbo* processing to much more general channel conditions and impairments.

Impressive performance has been achieved by applying *Turbo* processing to joint equalization and decoding, joint detection and decoding in fading channels, and joint multi-user detection and decoding. The ability to reliably recover transmitted data in such severe conditions has resulted in the need to develop robust synchronization techniques. One possible solution is to include the critical synchronization functions within the *Turbo* processing. Development of ultra-efficient link and physical layer protocols has become important, because, as a consequence of transmission techniques that practically achieve capacity, new R&D is being generated to address inefficient protocols.

3.6 *The Channel*

3.6.1 Introduction

The telecommunications system model presented in Technology Trends delineates *The Channel* as encompassing everything required to interface encoded source information with the transmission medium, delivering 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;
- wired media.

3.6.2 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 optical and infrared.

Key research and technology issues for the next five to ten years in radio propagation include:

- emerging broadcast and mobile services for both terrestrial and satellite delivery systems, and non-geostationary (NGSO) satellite systems;
- special considerations for new services, such as reception within buildings and vehicles of broadcast-satellite and mobile-satellite signals;
- cellular and microcellular applications, including in-building propagation; terrestrial "wireless cable" systems (e.g., LMCS);
- progression of telecommunication systems to higher frequencies, such as Ka-band and possibly Q/V (40/50-GHz) bands for satellites, and 60 GHz for indoor use;
- propagation impairments of concern to small-margin satellite systems such as VSATs and USATs;
- possible deployment of high-altitude space-borne platforms; interference between systems;
- EMC/EMI; and frequency allocations and standards;

Improved models for estimating channel impairments and techniques for adaptive impairment mitigation are prime requirements for successful implementation of future systems, especially at higher frequencies and for applications such as vehicle control systems.

3.6.3 Antennas

The dramatic uptake in wireless systems such as PCS and GPS has generated demand for miniature antennas — a demand that is continuing with the emergence of personal wireless communications devices offering a diversity of other services. Key to the successful deployment of rapidly emerging systems such as LMCS and Ka-Band satellites will be the availability of low-cost, easy-to-install, unobtrusive antenna systems. The antennas for both base stations and consumer terminals will be expected to meet increasingly sophisticated requirements, such as tracking and null steering, in order to provide coverage in high fade situations at high frequencies, and for interference suppression between systems. These technical requirements will be further complicated by the desire to maintain aesthetically acceptable antennas, in view of their rapid proliferation in consumer environments. Areas of technology development, with special attention to Ka-band and higher, over the next five years will likely include:

- Flexible performance and adaptive characteristics; efficient use of spectrum through greater directivity, beam steer-ability; shaping and control of beam coverage patterns, and the ability to null unwanted signals; active arrays; increased use of digital signal processing and "intelligent" antennas.

- Integration of electronics and antennas: combined circuit/antenna design solutions and software; for millimetre waves, inclusion of antenna elements on semiconductor materials with the electronics in some cases including digital signal processing or opto-electronic circuitry for pattern control and signal distribution; use of spatial power combining at higher frequencies.
- Antenna Aesthetics: new ultra-miniature UHF antennas; improved software and materials to handle complex and somewhat arbitrary shapes presently not possible at higher frequencies, increased use of approaches based on optical techniques such as lenses.

3.6.4 RF Electronics

Developments in RF electronics will increasingly be driven by the move to higher frequencies, the requirement to reduce physical size, power consumption, component and subsystem costs, and to enhance user mobility. Specific areas of technology development include:

- the increasing speed of silicon-based processes will accelerate improved functionality, resulting in integrated analogue and digital subsystems "on-a-chip";
- low power consumption techniques and high efficiency, miniature batteries to meet the demands of portable communicators;
- the computational and RF power capabilities and the speed of silicon-based devices are forecast to almost double in five years and triple in ten years, allowing digitization of receivers directly at RF and improving functionality to meet increasingly complex requirements;
- demand for wider wireless bandwidths will require significant improvements in technologies at millimetre wave frequencies beyond 60 GHz.

3.6.5 Terrestrial Wireless Systems

The trend to personal communications and provision of broadcast services to mobile users is driving 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. Wireless cable systems such as LMCS can deliver wideband channels to businesses and homes, likely with two-way communication capability to support interactive services. Essentially services will become world-wide through integration of terrestrial cellular systems with LEO and GEO mobile satellites (e.g., IMT-2000), delivering virtually ubiquitous communications capability.

To exploit the above trends, substantially improved capabilities to model transmission channels, along with new techniques to identify 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 analogue to high-capacity digital systems at 6/4-GHz and higher frequencies, despite deficiencies in multi-path impairment modelling. In the future, terrestrial microwave systems will assume more of a backup role, as optical fibre becomes more prevalent.

In the optical field, indoor communication links for low-cost movable office networks, which have high data throughput, are EMI insensitive, and require no spectrum license, are increasing in popularity. The severely impairing effects of the atmosphere limit the application of free-space optical links for outdoor communication. Trends in free-space optical links include: higher-power, eye-safe sources; high data rates; multi-path-survivable network configurations; non-line-of-sight links; and wavelength division multiplexing for isolation of close proximity nodes.

3.6.6 Satellite Systems

Until recently, satellite communication networks were implemented using a circuit-switched architecture provided by means of a relatively simple bent-pipe repeater aboard a geostationary satellite. Consequently, VSAT networks were based on a star topology, which necessitated double-hop interconnection of VSAT terminals via a master or hub station. To increase efficiency and provide a wider variety of interactive multimedia services, geostationary satellite systems are now capable of connecting small user terminals that are designed based on a packet-switched architecture. These satellites have advanced payloads incorporating on-board processing, switching and multiple beam antenna arrays. Some first generation on-board processors are already in orbit on satellites such as Inmarsat III and Hot Bird 4.

A relatively recent development is the introduction of networks based on constellations of non-geostationary satellites. Little LEO (Low Earth Orbit) systems, such as Orbcomm, provide low data rate store-and-forward messaging services. Iridium and Globalstar, two of the big LEO systems, will provide voice and data services to hand-held terminals by the end of 1998. Other planned non-geostationary systems, such as Teledesic and Skybridge, intend to provide high data rate multimedia services on a global basis within the next five years.

The development of these future satellite networks requires research in new technologies including satellite on-board processing and switching, multiple beam satellite antenna arrays, inter-satellite links and low-cost earth terminals. As new satellite communications technologies emerge, there will be an on-going need to design, analyze and demonstrate new system configurations, network architectures and user applications. Due to the ever-increasing spectral congestion in the conventional C and Ku-bands, many new systems are being planning for the millimetrewave bands (e.g., Ka, V and Q-bands) in order to take advantage of the large bandwidths available at these frequencies. Research is required to mitigate the adverse propagation effects in these bands and to develop system designs that will provide acceptable performance. In addition, R&D is required to develop the industrial base for the new technologies capable of exploiting the large bandwidths available at these frequencies.

3.6.7 Fibre Optic Systems

Optical fibre networks are presently providing commercial long distance carriers with a high bandwidth, large capacity backbone for telephony, (MCI, Sprint and AT&T for example). The operators strive to capture market share for enterprise traffic by deploying new technologies such as Wavelength Division Multiplexing (WDM), which lower the unit cost and price structure, resulting in higher traffic and network utilization. Carriers project an increase in traffic with a decrease in the cost of long distance calls, with the goal of providing rates as low as 1¢/minute! The market for WDM has grown from nothing to $1.3 billion over the last three years.

The nature of the traffic is also expected to evolve. Most of the current commercial traffic is voice, with a projected eight percent annual growth rate. The predicted growth rate of data communications is 35 percent a year, while traffic on the Internet is expected to double each year. Undersea fibre networks are currently transmitting 40 Gb/s over 8,000 km. Fibre optic WDM systems with over 100 channels are being deployed, providing more than 1.2Tb/s of carrying capacity. The trend toward greater capacity is expected to continue.

In spite of these successes, three main issues need to be resolved before WDM is fully deployed as a carrier medium of choice: standardization of wavelengths; cost reduction of WDM networks; and other "last mile" access solutions, possibly using wireless and low-cost fibre-line interconnection. Three factors may either accelerate or alter the utilization of WDM-based fibre optic networks: the emergence of short-haul use of WDM over the more conventional long distance super-trunk; the emergence of other WDM drivers; and the migration toward full network functionality.

The future will see an expansion of the capabilities of fibre and optical networks. Wavelength division multiplexing will be exploited in conjunction with other technologies, new modulation schemes, new methods to mitigate the performance-sapping effects that occur when fibres are no longer transparent, and perhaps a new generation of optical fibres. The jury is still out on whether passive WDM, all optical networks will be implemented.

Solutions to these issues are presently being investigated at the component level. Optical cross connections are under development, which will permit system restoration through optical switching. Wide bandwidth, low-cost EDFAs offer increased channels available to WDM. Quality of Service will be improved on the fibre optic network with a BER down to 10^{13}.

New technologies are on the horizon that will further simplify and enable WDM; fibre lasers and the use of advanced polymers will be exploited for applications such as switching, modulation, routing and component integration.

3.6.8 Wired Media

The deployment of fibre optics is forcing other wired media to support higher data rates. Recent deregulation and efforts to preserve existing investments in UTP and residential coaxial cabling are driving the trend to offer new services over wired media such as CATV and telephony cables. The evolution of wired media is intimately tied to the revolution currently happening in the subscriber local loop (access network). A second factor is the emergence of Gigabit Ethernet standards.

The last few years has witnessed a large increase in data rates possible over wired media such as UTP, copper wires, etc. Data rates of 155 Mbps over UTP-3 and 622 Mbps over UTP-5 are now possible. Existing copper loops can be reused with ADSL-1 (asynchronous digital subscriber line), a technology that can carry 1.5 to 2 Mbps up to 6 km over telephony cabling, or ADSL-3 which bridges about 2 km at a bit rate of 6-8 Mbps. As expected, these increases are generally coupled with decreases in the distance over which such data rates are possible. Very-high-speed DSL (VDSL) – a technique under development – promises 26 Mbps over 600m or 52 Mbps over 240m of copper pairs. Except for CATV coaxial cable, the future of wired media seems to be confined primarily to short distance intra-building communication and to the tail-end of the subscriber local loop.

In support of the new services planned for home delivery and the growing range of communications equipment to receive them, new network technologies are being deployed. These include networks that bring fibre to the curb, with coaxial drops, high-speed, HDSL, ADSL and VDSL – referred to as XDSL networks, using twisted pair copper drop cables and hybrid fibre coaxial cable networks. The wireless component has been described elsewhere in this Section.

Key technical issues to increased data rates over copper media include:

- limited bandwidth (e.g., 100 MHz for Category 5 UTP);
- severe attenuation above 100 MHz on Category 5 cabling (e.g., above 112 MHz, noise or cross-talk often exceed signal level);
- no standardized signalling applications, either released, pending, or in development, that specify UTP components.

Coding is therefore a key enabling technology for evolution of wired media. Advances are required in baseline wander cancellation, cross-talk minimization and noise immunity. In the example of Gigabit Ethernet over UTP, the big challenge is to develop a cost-effective signalling technology permitting extremely high data rate transmission over 100 metres using four pairs of Category 5 cabling when a pair can only support 100 MHz. The 802.3z Gigabit Ethernet Task Force acknowledged that complex analogue/digital circuit technology (about 250K gates) must be developed for Ethernet packets to run over UTP copper at gigabit per second speeds.

3.7.1 Introduction

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

3.7.2 Computing and Computation

Research and development into high end computation is providing the foundation for both major advances in supercomputers and the commercial development of hardware, software, and spin-off technologies for desktop and mid-range computers. By the early part of the 21st century, computers will be capable of peak performances in the teraflops range with terabyte storage technology. After 2010 computers are expected to reach petaflops processing levels, with exabyte mass storage. High end computing research will explore advanced concepts in quantum, optical, and biological computation technologies. In addition, similar performance enhancements will be made using existing technologies such as high temperature super-conducting materials, molecular electronics, and application of optical interconnection to intra and inter-chip communications. The overall power and processing throughput of personal computers and workstations is expected to continue increasing by roughly a factor of two per 18 months beyond 2010.

Development will continue on Massively Parallel Processing (MPP) architectures, with corresponding operating systems and software applications capable of exploiting MPP architecture. These developments will be exploited for workstations and personal computers, resulting in cost-effective, major improvements in processing throughput capabilities. In turn, this will demand faster and more intelligent computer networks and inter and intra-computer telecommunications hardware. New approaches will be explored for the implementation of MPP architecture and the development of innovative parallel systems software, operating systems, languages and compilers, and large scale (terabyte and larger) data management.

To effectively benefit from the types of increased processor speeds and throughputs anticipated by the above developments, concurrent advances will occur in the design of computer operating systems and software, the development of intelligent systems, and basic computer hardware architectures. One specific type of MPP, Parallel Distributed Processing (PDP) or artificial neural networks consisting of large numbers of interconnected and co-operating processing units trained through the use of learning algorithms, is expected to receive attention and focus for medium to long-term developments of intelligent systems. Distributed systems will emerge, in which components of an information processing task are allocated to physically separated computers. These systems will require software that allows the client computer to do as much of the processing as possible, while hiding much of the communication between the server and applications developer.

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. The "size" of software packages tends to obey its own version of Moore's Law, i.e., the hard disk space required to install the software approximately doubles with each new version of the software, typically annually. To deal with these issues, Formal Description Languages are being developed that will automatically translate a software specification into executable code. To ensure that the software has correct syntax and semantics, validation techniques are being developed. Finally, to ensure that the software does indeed fulfil its intended functions, conformance-testing techniques are being developed. These will form important tools in Computer Assisted Software Engineering (CASE). The development of "paralleled" compilers and computer languages is expected to simplify and reduce future computer code.

3.7.3 Electronics Materials, Devices, Components

The major trends in this category are largely driven by the desire and need to maximize the functional complexity achievable within a given size and power constraint. Some highlights are outlined below.

- By far the dominant factor in this area will be the continuous increase in the functional power and speed of the workhorse CMOS based Silicon ICs. The recently published Semiconductor Industry Association Technology Roadmap foresees the production of commercial silicon-based devices with dramatic advances in performance as summarized in the following table.

	YEAR		
ITEM	1997	2003	2012
DRAM Memory Capacity	267Mb/chip	4.3 Gb/chip	275 Gb/chip
Microprocessor Size	11 MTrans/chip	76 MTrans/chip	1.4 Btrans/chip
On-chip Switching Speed	750 MHz	2.1 GHz	10 GHz
μP Cost per Million Transistors	$2.90	0.56¢	$0.047
DRAM Cost per Million Bits	0.06¢	0.75¢	0.03¢

- New devices such as heterostructure (SiGe) bipolar transistors (HBT) and quantum well devices may offer even higher speeds in specialized applications. Systems based entirely on photonics will offer a further increase in speed. Power consumption per chip will continue to be a problem, as the increased functionality per chip will override improvement in power efficient design approaches and operating voltages as low as 0.5 V. A key issue will be the development of new techniques for moving information on and off chip.
- The "system-on-a-chip" (SOC) will become a reality with the convergence of analogue, digital and opto-electronics component technologies and the resultant integration of all three into integrated subsystems. This will require more R&D to find technologies, architectures and design methodologies that maximize the performance in mixed function operations. Greater collaboration between large IC designers will be necessary, as costs become prohibitive to redesign increasingly sophisticated macro-functions for use in such SOCs;
- There will be increased R&D into multi-layer "motherboard" techniques such as the promising, low temperature, co-fired ceramic (LTCC) techniques which are just beginning to emerge. In addition, there will be new efforts to combine devices that use different semiconductors and device types such as Si CMOS, SiGe bipolar and GaAs and GaAs heterostructure bipolar to achieve exceptional performance.
- R&D will continue on new semiconductor materials such as Indium Phosphide (InP) for specialized devices requiring higher speeds and opto-electronic functions. There will be heightened emphasis on low power consumption circuitry, reduced thermal dissipation and higher efficiency, high density batteries and power storage devices to meet the demands of portability, as well as for devices such as RFID and smart tags.
- Semiconductor micro-machining techniques will permit acoustic functions, pressure and motion sensing devices and other electro-mechanical functions to be integrated "on-wafer" with other electronic functions.
- Low loss electronic circuitry will begin to emerge at millimetrewave frequencies up to 100 GHz, driven primarily by the transportation industry applications such as collision avoidance and proximity detection in vehicle control applications.

4.0 Impact of Social and Environmental Issues on Technology

4.1 *Introduction*

While communications technology development has the potential to create environmental and social problems as well as opportunities, emerging societal and environmental issues have some influence on the development of communications technology. This section briefly identifies some of these issues that have an impact on the future development of communications technology.

4.2 *Privacy Issues*

The right to personal privacy is a tenant of the Canadian Charter of Rights and Freedoms. However, the guarantee of this fundamental right is becoming ever more difficult to protect as the Internet and wireless communications systems grow exponentially.

The interconnection of networks increases the flow of personal and business-related information. Existing data – including electronic transactions, credit records, financial accounts, educational, medical and driving records – may be reused to develop comprehensive profiles of individuals or companies. These records can be sent across national borders and sold or integrated with other databases.

Manipulation of data may occur without the consent of the individual from whom it was collected. Moreover, the information is often used for purposes unrelated to those for which it was originally collected. Due to the enormous potential for abuse, there is a need for effective privacy protection.

Electronic media are increasingly being used to send unsolicited information, spurring complaints of invasion of privacy. Electronic messaging technology needs to be developed and applied to maintain the individual's right to privacy. In personal radio communications, it is illegal to eavesdrop on telephone conversations over wireless personal communications channels using digital scanners.

4.3 Security Issues

Security is a basic feature of any public communication infrastructure, fostering consumer confidence and economic opportunity and upholding democratic values. A secure environment provides confidentiality to conduct financial, medical and other sensitive transactions over a telecommunication network.

For electronic commerce to develop as an entirely new economic sector, the need for security is of utmost importance. Free flow of trade and information on the telecommunication networks benefits electronic commerce. However, firms must be able to verify the identity of customers and other firms with which they are doing business.

Many companies are currently using the Internet for electronic data interchange. A 1997 U.S. survey projected that Internet sales would rise by 1,000 percent over the previous year, approaching $330 billion U.S. in value by 2002. Similar trends are expected in Canada. Despite the tremendous growth, issues of security and privacy are still viewed as deterrents. According to a recent Industry Canada survey, 46 percent of respondents rated security and privacy concerns as important/very important. Many organizations and individuals are working on the assumption that the Internet is an insecure network.

Growing use of electronic media for storing personal information has prompted concern over the vulnerability and security of government databanks. With the development of wireless access to computers, the security of electronic data files is exacerbated.

Currently, a variety of commercial technologies are being deployed to help users guard against Internet risks. These include solutions focused on securing authentication, authorization, confidentiality, proof of receipt, and digital signatures. Such measures have become paramount and technology has an important role to play in improved telecommunication network security.

There are also political issues, under consideration by various national and international fora, concerning the export of encryption algorithms, law enforcement agency access, and the illegality of any form of encryption in some countries, among others.

Finally, in the Information Age, the functional operation of an entire society, encompassing government, industry, and the individual relies increasingly on computer and communications networks. These networks can be vulnerable to disruption through natural disasters or deliberate actions, so it is vital that they are designed to survive such circumstances.

4.4 Regulatory Issues

The introduction and application of new technology can be hindered by outdated communication regulations, standards and policies. Governments have been moving in the direction of changing the regulatory and socio-economic framework so that new technologies can be introduced with minimal hindrance and delay. Spectrum license fees and auctioning are mechanisms regulators are using to stimulate competition among communications service providers to develop different systems and new technologies for the market, within broad guidelines. Standards and regulations are changing so that radio communication equipment specifications do not restrict the introduction of specific equipment, but define boundaries of operations to prevent interference. This policy change and new regulatory framework is designed to promote R&D, greater competition, and improvement of services. This new environment has also been characterized by some companies as confusing, beneficial to large established players and a detriment to entry for dynamic, yet considerably smaller, innovative companies.

Another impact that regulatory issues have on technology is in the area of spectrum allocation. While the allocation process considers technological capabilities and user demands, the R&D activities for specific technologies are largely driven by spectrum availability.

4.5 *Environmental Issues*

Generally, communications technology is a relatively benign contributor to environmental pollution and can assist in reducing environmental pollution. However, with the tremendous growth of the personal communications segment, a number of issues need to be addressed.

Global growth in electrical and electronic equipment use is heightening the background levels of electromagnetic fields that are present everywhere in the environment. Spurious electromagnetic fields can interfere with the operation of communications equipment, as well as medical equipment in hospitals. Potential malfunction due to signal impairment can also occur with remote control vehicle systems that are dependent on communications systems. This will limit the opportunity for development of such systems in the future.

The potential biological hazards of long term exposure to low level electromagnetic fields is a controversial issue that requires much more study. Research needs to be done on radiation from hand-held devices, as well as the aggregate effects of radiation from numerous transmitters operating in the same neighbourhood. Limits on electromagnetic field strengths are required and have an impact on the design of communication equipment and systems. It will be necessary to demonstrate that communication equipment is compliant with recommended safe exposure levels.

For aesthetic reasons, communities are less tolerant to visual clutter of large antenna structures. Service providers need to be more creative in the deployment of antennas in strategic locations, and researchers need to be more innovative to minimize antenna sizes so that they blend more harmoniously with the environment.

4.6 *Cultural Issues*

The trend in communications is toward global access for the exchange of information and cultural products between Canadians and people around the world. Canadian cultural industries face increased competition, but there is growing opportunity for 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.

Growing global information push has created the need to filter unwanted sources. Many people feel overloaded with information now, and have difficulty discerning useful information from the increasing flood of electronic junk. New filtering software, or perhaps entirely new institutions may need to be developed to address this situation.

Television and other image-based media are believed to affect the behaviour of some people. While advanced television and CD quality digital radio will significantly improve entertainment qualities, issues such as youth violence and literacy and numeracy problems are possible negative repercussions of excessive television viewing. It is expected that the public will demand further research on these topics.

4.7 *Economic Issues*

Canada has a rapidly growing information-based economy, with information and communication technologies (ICT) the lead drivers. In 1996, the ICT sector contributed 7.2 percent to Canada's GDP and 37.3 percent to R&D. From 1990 to 1996, the compound annual growth rate of the entire Canadian economy was 1.5 percent, while the corresponding rate for Canada's ICT sector was 7.6 percent. Much of Canada's future prosperity will depend on technology adoption, especially in the new services sector.

Information and communication technology creates diversity and empowers individuals, and levels the playing field between small and large corporations. Governments will be required to foster an environment where individuals can use electronic technology to enhance business productivity and to develop information products and services.

Telecommunications is one of Canada's fastest growing sectors and it will play a larger role in the future, generating both products and services. Currently, cellular and PCS service providers in Canada are required to invest two percent of their adjusted gross revenue on related research and development activities. This represents hundreds of millions of dollars over the next five years and will have a significant impact on Canada's R & D performance.

Globalization will create vast opportunities for Canada and other countries that are capable of participating in the Information Age. To capitalize on these, Canada must develop a culture of life-long learning and create an education system that stimulates its students to pursuing science and technology interests at a young age. It also needs to ensure that R&D funding is available to develop both contents and technologies for the knowledge-based economy of the 21st Century.

5.0 Relative Importance of Technologies to Progression of Global Trends

The mandate of the group did not include making recommendations for R&D activity. However, committee members felt that an attempt should be made to qualitatively assess the degree of importance each technology area would require to ensure continued progress in each of the *Global Trends*. A new row for *Convergence* was added. In addition, it was noted that the committee had somewhat modified the interpretation of *Global Trends #1 and #2* and this resulted in a modest change in the evaluations in these rows.

TABLE 1: Relative Importance of Technologies to Progress in Global Trends

		TECHNOLOGIES					
		1 User Interface	2 Source Signal Processing	3 Networking	4 Transmission Signal Processing	5 Channel	6 Base Technologies
GLOBAL TRENDS	A. Ubiquitous Communications	M	H	H	H	H	H
	B. Global Communications /Networking	H	L	H	M	M	H
	C. Machine-Machine Communications	L	L	M	M	M	M
	D. Natural Human-Machine Interfaces	H	M	L	L	L	H
	E. Broadcast, Information and Entertainment Services	H	H	M	M	M	H
	F. Convergence	H	H	H	H	M	M

CLASSIFICATION: High: R&D in this area of technology is highly important to progress in this Global Trend.
Medium: R&D in this area is important to progress in the Global Trend and some significant issues need resolution. Progress will be reliant on progress in other Global Trend areas.
Low: Progress in this technology area is not vital to progress in this Global Trend.

Appendix I

List of Acronyms and Abbreviations

μP --------- Microprocessor

3D -------- 3 dimension

AAC ------ Advanced Audio Coding

ADSL ------- Asynchronous Digital Subscriber Loop

AVL ------- Automatic vehicle location

BER -------- Bit error rate

BPSK ------- Binary Phase Shift Keying

C3 -------- Communications, Command and Control

CANARIE --- Canadian Network for Advancement of Research, Industry and Education

CASE ------ Computer Assisted Software Engineering

CATV ------ Cable Television

CATV ------ Community antenna TV

CD -------- Compact disc

CDMA ----- Code Division Multiple Access

CME ------ Continuing medical education

CMOS ----- Complementary metal oxide semi-conductor

CRT -------- Cathode ray tube

DAT ------- Digital Audio Tape

DCT ------- Discreet Cosine Transform

DRAM ------ Digital random access memory

DVD ------- Digital Video Disk

EDFA ------- Erbium Doped Fibre Amplifier

EHF -------- Extremely high frequency(30 GHz-300 GHz)

EMC/EMI --- Electromagnetic compatibility/interference

ETC -------- Electronic toll collection

Exabyte ----- 10^{18} bytes

FET -------- Field Effect Transistor

GaAs ------ Gallium Arsenide

Gb/s ------ Gigabits per second

GDP ------ Gross Domestic Product

GEO ------- geosynchronous earth orbit

GHz ------ GigaHertz (10^9)

GPS ------- Global Positioning System

HBT -------- Heterostructure Bipolar Transistor

HDSL ------- High Speed Digital Subscriber Loop

HDTV ------ High Definition TV

HTML ------ Hypertext Markup Language

IC --------- Integrated circuit

ICT -------- Information and communication technologies

IMT -------- International Mobile Telephony

InP -------- Indium Phosphide

ISDN ------- Integrated services digital network

ISO/IEC ---- International Standards Organization

ITS --------- Intelligent transportation systems

ITU -------- International Telecommunication Union

JPEG ------- Joint Photographic Experts Group

Ka-Band ---- 18-26.5 GHz (sometimes refers to 20/30 GHz Satcom)

kms -------- kilometres

LAN ------- Local area network

LEO -------- low earth orbit

LMCS ------ Local Multipoint Communications System

LPC -------- Linear predictive coding

LTCC ------ Low temperature co-fired ceramic

MBPS ------ Megabits per second

MPEG ------ Motion Picture Experts Group

MPP ------- Massively Parallel Processing

NGSO ----- Non-Geostationary Satellite Orbit

NREN ------ National Research and Education Network

OCR ------- Optical character recognition

OFDM ----- Orthogonal Frequency Division Multiplexing

PC --------- Personal Computer

PCN ------- Personal communications networks

PCS ------- Personal Communications Services

PDA ------- Personal digital assistant

PDP -------- Parallel distributed processing

Petaflops ---- 10^{15} floating point operations per second

Q-Band ----- 36-46 GHz

QoS ------ Quality of Service

QPSK ------ Quadrature Phase Shift Keying

R&D ------- Research and Development

RF --------- Radio Frequency

RFID ------- Radio Frequency Identification

SCADA ----- Supervisory Control and Data Acquisition

SDTV ------- Standard Definition TV

SiGe ------ Silicon Germanium

SOC ------ System-on-a-chip

Tb/s ------- terabits per second

TDMA ------ Time Division Multiple Access

Teraflops ---- 10^{12} floating point operations per second

UHF ------- Ultra High Frequency

USAT ------ Ultra small aperture terminals

UTP -------- Unshielded twisted pair

V-Band ----- 46-56 GHz

VCR ------- Video Cassette Recorder

VDSL ------- Very-High-Speed Digital Subscriber Loop

VR -------- Virtual reality

VRML ------ Virtual Reality Modelling Language

VSAT ------- very small aperture terminals

WDM ------ Wavelength Division Multiplexing

WWW ----- World Wide Web

WYSIWYG -- What you see is what you get

XDSL ------- "Any" Digital Subscriber Loop (DSL)

Appendix II

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