TECHNOLOGY ENABLERS AND IMPACTS
on Next Generation Business Solutions
and Communication Services

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Sponsored by
AT&T SOLUTIONS
AT&T BUSINESS MULTIMEDIA SERVICES

15 June 1995
Version 2.5

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1. Introduction and Theses

Many AT&T customers are finding that the radical changes occurring in information technology create both opportunities and threats for their own businesses. The effective use of IT (Information Technology) can provide important competitive advantages, and IT can make it practical to decentralize and globalize complex enterprises to take advantage of favorable economics.

AT&T planners have been developing their own vision for technology evolution and its impacts beyond the year 2001, in the course of addressing AT&T’s need to redefine many of its own offerings. This paper shares a snapshot of that vision, primarily from the “technology push” point of view, but connected strongly to “market pull” as communicated by AT&T customers. The main goal is to characterize the rapidly developing technologies that are agents of change for IT, and to convey a feeling for the changes wrought on business and consumer environments. The IT drivers typically overlay other powerful industry forces - specific to each business - that may prompt them to reconfigure.

Many AT&T business customers found it useful to share an earlier version of this paper that appeared almost three years ago. Like AT&T, they needed to evaluate potentially pivotal IT impacts on their own businesses - typically enabled by the same information technologies that drive AT&T’s own businesses. The accuracy of the original version endured well, but some updates and the addition of new material - on multimedia especially - were needed. Intervening press attention has popularized “paradigm shifts”, the “information superhighway”, and some important aspects of IT evolution ad nauseum. This suggested tuning up the emphasis to help readers to understand developments in the trade and popular press.

1.1. Information Technology Impacts on Businesses

AT&T needed to answer the following question for its own purposes:

• Which information technologies are the most important enablers for AT&T’s largest business - communications services?

The answers potentially fall into three impact areas:

• Technology that improves internal operations (such as billing, creating new services, provisioning services, managing the network in real-time) with the effect perceptible as improved quality, price, and performance.

• Technology that changes the basic form and balance of AT&T businesses. For example, new, more capable customer equipment can change the value of switching and transport, and enable non-traditional competitors.

• Technology that directly supports new communication service products, such as broadband fast packet services, multimedia collaboration services, information retrieval services, and improved ease of use.

Extensive market research and analysis narrowed the range of technologies to a group related to services most likely to satisfy customers (partially represented in Figure 2).

For many of AT&T customers’ businesses, information technology impacts map onto three areas (see Figure 1) that are roughly congruent to those above:

• Internal business processes, e.g.: operations productivity improvement and automation, supplier integration, improved decision support, support for decentralizing around virtual offices, empowering individuals...
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- **New markets, customers, and business models**, e.g.: partnering and integrating vertically through traditional and electronic alliances, exploiting business convergences, meeting stronger and non-traditional competition, expanding global reach, using electronic sales media...

- **Products and services to customers**, e.g.: higher technology content, improved quality, added uses, expanded variety, shorter time to market...

Customers find that the important IT enablers likely to affect them (with business-specific spin) are much the same as those AT&T needs to consider in inventing next-generation AT&T services that address their needs. IT is, quite generally, a force multiplier for people, a glue for distributed enterprises that weren’t feasible before, a way to assimilate new manufacturing techniques, a way to be more responsive to customers, a way to enter non-traditional markets, and a way to respond to more intense competition on traditional home ground. Nowhere is this more evident than in the IT industry itself, where products and services become commodities almost upon conception.

**Figure 1: INFORMATION TECHNOLOGY IMPACTS ON BUSINESSES**

1.2. **Information Technology Prognosis (Push)**

The IT industry is in the midst of two simultaneous, uniquely rapid revolutions that will bring ubiquitous, cheap computing intelligence and affordable, flexible, broadband, transparent, intelligent networking. The formerly separate computer and communication industries are beginning to overlap progressively and will merge in the future.

Explosive growth in the basic technology enablers for IT will continue unabated for the rest of the decade and beyond. Continuing order-of-magnitude improvements in the price/performance of basic technology supporting both computing and communications will allow new applications riding on them to be ubiquitously dispersed.
Much of the luxurious new capability will appear as improved usability: more natural interactions with machines, ease of use, automatic user adaptation, mobility with anytime, anywhere connections. Most notably, vivid, entertaining affordable multimedia/visual capability will appear in business and consumer markets, in the guise of user interfaces, new and reworked applications, and faster, improved communications services that add more value.

Historically crucial compute versus communicate cost tradeoffs will cease to dominate decisions as both become dramatically more affordable. Computing (stand-alone) versus communicating (networked) solution will be adopted based on ease of use, timeliness, the need for personal contact, human resources availability, economy of scale, and organizational and personal style rather than cost alone. This facilitates workplace collaboration at a distance, and decentralization of enterprises and communities.

Most businesses (especially communications companies) must learn to use the new technology aggressively and creatively to differentiate their offerings from those of traditional and non-traditional competitors. In addition, consumer appliances, particularly video-capable ones, are acquiring digital and computer-like capabilities - thereby allowing new applications that combine computing with broadband access to appear.

Figure 2 sketches the performance trends for a set of key technology enablers that will be described further in sections that follow. Some of them are seminal, while others reflect platforms and application support capabilities that are becoming newly practical for mass-market distribution, typically due to the price/performance improvements in computing and communications.

1.3. Seminal Technologies

The two seminal technologies that are the principal agents of change are:

- **Microelectronics** - electronic (primarily silicon) integrated circuit technology (including processors and memory).  

- **Photonics Technology** - lightwave devices (including optical fiber and the devices that make it usable).

We are witnessing both computing and communications revolutions - as a first approximation, microelectronics drives computing progress, while photonics along with silicon IC improvements (especially signal processors) drives the communications side.

- **Software Technology** is often included as a third seminal contributor to the IT revolution, referring to tools that should make it easier to create reliable, creative, complex programs on affordable budgets and schedules, built by programmers who need not be superhuman. While taking this view, it’s important to realize that Innovative algorithms and software, require cheap platforms (computing and communications hardware) to have mass market potential.

Most of the other technologies mentioned below trace their expected practicality to these. For example, the emerging multimedia technologies depend on IC progress that will make it affordable to embed video compression and speech recognition into desktop platforms. Multimedia communication depends also on affordable transmission on lightwave, coaxial, copper pair media, and on broadband switch technologies - founded on progress in photonics and electronics technology. Multimedia applications depend additionally on software that supports collaboration and user interface improvements, rendering the technology usable to customers.

The integrated circuit and photonics technologies depend in turn on more basic R&D in materials science, optics, physics, chemistry, lithography, and many others. Two of these areas are singularly critical:

- **Materials and Manufacturing Technology** advances applied to ultra-pure materials and thin films made the integrated circuit and storage technology density revolutions possible. To manufacture integrated circuits cost-effectively, it is necessary to grow large crystals of ultra-pure materials, and then use vacuum deposition techniques to grow complicated sequences of tightly controlled impurity layers while meeting harsh requirements.
on uniformity and reproducibility. Magnetic storage media (used in disks and tapes) rely on ultra-pure, defect-free films. Examples of IT's dependency on these somewhat unglamorous basic technologies are abundant.

- **Lithography** advances are driving the revolution in miniaturizing electronic and (more recently) optical components. Lithographic techniques are used to transfer a design that has been drawn and replicated using CAD (Computer Aided Design) tools onto a blank IC wafer using beams of light, electrons, or (eventually) x-rays or ions. Applied to silicon wafers, lithography has and will produce the generations of successively more dense integrated circuit chips (ICs) containing transistors and other electronic components. Applied to Gallium Arsenide (and Indium Phosphide and related materials), lithography produces high speed electronic ICs but, with especial importance, has also begun to produce miniature optical components such as fixed and tunable lasers, photodetectors, lenses, diffraction gratings, modulators, etc. In conjunction with optical fibers, these can revolutionize communications, by making possible cheap wide bandwidth applications. Lithographic miniaturization has also begun to be applied to mechanical devices: these will probably not affect the information industry in the near future, but may have important medical applications.

Lithographic progress is measured by the size of the smallest feature that can be reliably created on a wafer, measured in 'microns'. One micron is one millionth of a meter (1 meter = 39.37 inches). A 1 micron line would include about 5 - 10 thousand molecules lined up in a solid or on a surface.

The sections that follow discuss the key enabling technologies individually.

**Figure 2: ENABLING TECHNOLOGY EVOLUTION**

1.4. **Paradigm Shifts**

By the end of the century, cumulative progress in IT will support a shift our mental model ('paradigm') for the way we use and interact with computers. Figure 3 summarizes these along with several previous shifts in the human-computer relationship since the 1960s, when 'computer priesthoods' became widespread. By 2000+, human interactions with machines will begin to closely approximate natural ones. Much of the technology progress supplied by the twin revolutions in cheap, miniaturized processing and flexible, broadband communications will be allocated to ease of use, mobility, and the incorporation of imagery and video.
Communication networks will parallel the paradigm shift in desktop capability by embracing more adaptive and user-friendly features and services, in addition to providing cheap, high bandwidth transport. Low cost intelligence and memory can and will find applications almost everywhere.

**Figure 3: NEXT GENERATION IT PARADIGMS**

<table>
<thead>
<tr>
<th>DECADE</th>
<th>1960s</th>
<th>1970s</th>
<th>1980s</th>
<th>LATE 1990s - EARLY 2000s</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARADIGM</td>
<td>BATCH + MEDIUM SCALE</td>
<td>TIME SHARING + LARGE SCALE</td>
<td>DESKTOP TV SET-TOP + VERY LARGE SCALE</td>
<td>BOUNDARYLESS MULTIMEDIA NETWORK + ULTRA LARGE SCALE</td>
</tr>
<tr>
<td>ELECTRONICS INTEGRATION</td>
<td>&gt; MAINFRAME + TERMINAL ROOM SLOW</td>
<td>&gt; MINICOMPUTER + SPECIALIST REMOTE ACCESS</td>
<td>&gt; PC WORKSTATION + DESKTOP PERSPECTIVE</td>
<td>&gt; PALMTOP, MOBILE, TRANSPARENT EVERYONE</td>
</tr>
<tr>
<td>COMPUTER ACCESS USER INTERACTION</td>
<td>&gt; PUNCH &amp; TRY + ACCESS</td>
<td>&gt; EDIT TEXT</td>
<td>&gt; PRESENT</td>
<td>&gt; USE INFORMATION MASTERY FULLY INTERACT AND SIMULATE</td>
</tr>
<tr>
<td>OBJECTIVE OPERATIONS</td>
<td>&gt; CALCULATE + ORGANIZE &amp; PROCESS</td>
<td>&gt; DIALUP + SLOW</td>
<td>&gt; GRAPHICAL LAYOUT</td>
<td>&gt; VIRTUAL, UBQUITOUS</td>
</tr>
<tr>
<td>NETWORK CONNECTIVITY ENDPOINTS</td>
<td>&gt; PREMISES + HARDWIRED &amp; SLOW</td>
<td>&gt; TERMINALS</td>
<td>&gt; LANS, PRIVATE NETS + HARDWIRED &amp; 1 AS</td>
<td>&gt; BROADBAND ON DEMAND, LOCAL WIRELESS ACCESS</td>
</tr>
<tr>
<td>DATA ITEMS LOCATION ORGANIZATION</td>
<td>&gt; ALPHA-DECIMAL + CARDS &amp; TAPE</td>
<td>&gt; TEXT &amp; VECTOR GRAPHICS + DISK</td>
<td>&gt; SERVERS &amp; FLOPPY DISK + RELATIONAL</td>
<td>&gt; INTEGRATED IMAGE, VOICE VIDEO, SCRIPT</td>
</tr>
<tr>
<td>SOFTWARE TECHNIQUES</td>
<td>&gt; CUSTOM + SEQUENTIAL</td>
<td>&gt; PROPRIETARY &amp; STANDARD + SEMI &amp; BASIC</td>
<td>&gt; COMMODITY PACKAGES + C &amp; PASCAL</td>
<td>&gt; GROUPWARE, AGENTS, &amp; OPEN SYSTEMS</td>
</tr>
<tr>
<td></td>
<td>&gt; COBOL &amp; FORTRAN</td>
<td></td>
<td></td>
<td>&gt; C++, REUSABLE PARTS, &amp; OBJECT ORIENTATION</td>
</tr>
</tbody>
</table>

Even the boundaryless multimedia networked paradigm (Figure 3) is still overtly one of a human to a smart machine. Sometime beyond 2001 this will change. Two paradigms now just emerging are likely to remain, echoing as they do now the complementary worlds of a smart, automated (office or home) environment and a simulated world of the imagination. Both try to shield users from the need to be overtly aware that they are using sophisticated computing machines: as Arthur C. Clarke put it: “any sufficiently advanced technology is indistinguishable from magic”:

- "Ubiquitous Computing": Computing devices become embedded ubiquitously in both commonplace and new objects about the office, home and mobile environments. In offices, they include a kind of electronic paper that is present everywhere but has been invisibly merged into the background. There might literally be hundreds of computers in an office, networked over short-range wireless channels. These serve as electronic scratch pads, blackboards, notebooks, etc. They can be grabbed, moved around, laid out on tables, and otherwise used like their paper ancestors while capturing the work done on them and the user’s identity. Active badges and a host of other auxiliary convenience devices could keep track of many workaday details of our own and other people’s
activities. Similarly, homes acquire "brilliant" appliances and perhaps an infrastructure of sensors coupled to unseen electronic personal servants. To be fully practical, this notion depends on major price/technology innovations in power supplies and in really cheap, good flat panel displays.

- **Virtual Reality:** A complementary vision for offices and homes that is an advanced form of today's simulations - these range from video games to aircraft design and performance models. VR removes users from direct experience of the world around them. It replaces reality by mimicking real or imaginary worlds inside the computer, and immerses users in them using display devices that insulate the senses from their immediate surround, making it extremely computation-intensive and possibly also requiring expensive gear for interacting with people (helmets with built-in displays, instrumented gloves, etc. for the purists) to make the illusion convincing. The Startrek TV show popularized the 'holo-deck' - a form of virtual reality that fools all the senses without body contact terminals and that is so advanced it may really have to wait until the 24'th century.

Business will find important VR applications in visualization, but VR may not be well-adapted for bringing people together in ordinary business relationships. On the other hand, virtual reality is widely dispersed today in the form of video games that ensnare almost every child and young adult. When that generation enters the work force, VR for visualization and information access will become the expected interface for adult users.

There is probably no historical precedent for price/performance improvement in a broadly applicable technology over so many (say 6 - 8) orders of magnitude in 50 years. This technology injection is an impulse whose impact will take decades to assimilate. The outcomes for business, social structures and life styles are not foreseeable in detail, but are virtually certain to reorder the traditional values and balance. For comparison, the 1 - 2 order of magnitude improvement in food availability that was obtained by replacing hunting and gathering cultures by agriculture resulted in the creation of cities, governments, and the classical civilizations of Egypt, India, and China.

2. **Computing Technology and Systems**

Computing systems will continue to grow in power by several orders of magnitude during the rest of this century. We can count on a continuing IT technology revolution, driven by ongoing miniaturization of electronic components, expanding device complexity and performance, and declining cost.

Desktop business systems and brilliant consumer appliances will become ubiquitous and have already become more powerful than recent-generation mainframes. Much of the new power will go into improved ease of use, especially through widespread multimedia (graphics, imagery, video) capability and through voice command and control. As interactions with machines grow more natural, the systems and applications controlled will also become user-adaptive: machines adapting to people rather than the reverse. Computing devices will become progressively mobile, miniaturized, and communication-capable, filling needs to integrate them into the anytime/anywhere rhythm of daily business and personal life.

As great processing and networking power become universal, they will be embedded in devices whose ancestors were telephones, televisions and other consumer appliances, or computer workstations. With time, these classes of products will progressively overlap in functionality. As they converge they will compete with each other as alternate vehicles for IT technology - particularly with respect to multimedia applications. The historically separate products and functions brought to mind by client/server computing on LANs (Local Area Networks), CATV and video gaming consumer products, and telephone conferencing/PBX arenas will become blurry.

As computers become ubiquitous they will in some sense become invisible. When almost everything is a computer, how does it add specificity to say that an equipment item or appliance is one? The computer industry may become infrastructural - analogous to a transition that the mechanical parts industries made in the late 19th century.
2.1. Silicon Integrated Circuit Density

Since the first digital computing systems appeared in the late 1940s, improvements in them were traceable first to replacing vacuum tubes by transistors and subsequently to replacing discrete transistors and other components by integrated circuits (IC "chips") with progressively greater densities of components on them.

Transistors switch faster and draw less power than vacuum tubes and have replaced them for almost every electronic application except televisions and computer displays, where CRTs (Cathode Ray Tubes) still predominate.

Integrated circuits started to appear in electronic products during the early 1970's. Today, most IC's are digital and are used in computer applications, including processors embedded in intelligent products as well as the workstations that are central to the desktop revolution. Most modern communications is becoming digital and the equipment that supports it - including large switches - incorporates thinly disguised computing devices.

Figure 4 shows the rate at which computer memory capacity - a widely used measure of electronic component density on Silicon chips - has been increasing since the early 1970s. DRAM (Dynamic Random Access Memory) is the commodity memory used in most desktop computers. 'Dynamic' means that its contents are lost when power is turned off. The DRAM in peak volume production held 1 Megabit of data in 1990, using 1.0 micron lithographic technology.

By the decade's end, the 1 gigabit DRAM chip (< 0.2 micron feature size) will be in the early production phase. The 100 megabit chip (about .35 micron technology) will be the standard commodity chip used by industry. The slope of the component density curve is sometimes called 'Moore's Law' after Gordon Moore of Intel Corporation who predicted that IC density would double every two years. He was a bit too conservative so far. The doubling time is
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about 18 months, which yields a 100-fold increase per decade. For logic chips (e.g. microprocessors), the rate of density improvement is somewhat smaller (about 32-fold per decade).

Silicon will remain the material of choice for electronic ICs during the foreseeable future, despite the greater speed promised, for example, by Gallium Arsenide ICs. The enormous investment in silicon manufacturing technology and production gives it a decisive edge. ICs based on Gallium Arsenide or Indium Phosphide will have markets in photonics and for analog circuits such as those in wireless transceivers.

When will this density trend end? IC technology will not be pushing the physical limits for at least the next ten to twenty years. Quantum physics sets one such limit: components must contain some minimum number of atoms in order to behave reliably at room temperatures. The exact physical limit is not known but we will clearly not begin to approach it until well into the next century. The most important limits for the near future pertain to lithography. There are no barriers to miniaturizing features down to about 0.1 micron (corresponding to 4 gigabit DRAM's), but to draw features much smaller we will need the short wavelengths that x-ray or ion beam lithography will provide if they turn out to be workable commercial technologies.

2.2. Integrated Circuit Price Trends

While IC component density will continue quadrupling about every three years, the capital investment required for fabrication lines will increase markedly, exceeding about $1 billion for a fabrication line by the year 2000. The entry price to manufacturing will be even more prohibitive and some current IC manufacturers will be shaken out if they cannot count on mass markets.

In the past, IC's of succeeding generations cost the same (about three dollars per chip) while the density increased. As a result the cost per transistor (or other component) decreased in tune with advances in lithography, as shown in Figure 5a. The cost/performance trend will continue at least through the end of the decade, but at a slower rate, according to some experts, because future chips will roughly double in cost with each generation.

2.3. Microprocessor Evolution

Figures 5b and 5c show some performance and complexity trends for microprocessors. The clock rate - a measure of speed, has been increasing at about a factor of 10 per decade. Actual computing power will increase faster as the result of on-chip parallelism and pipelining. In 1990, a 1 micron technology microprocessor chip contained about 1 million transistors (e.g., Intel 486 @ 1.2 Million). The Intel P6 (1995), the Pentium's successor, uses 5.5 million transistors in its processing unit plus 15.5 million more in its dedicated 256 KByte SRAM (both on a multi-chip module done in 0.6 micron technology). The P6 is clocked at 133 Megahertz and offers about 250 MIPS. By the end of the decade, technology will allow a chip to hold about 100 million transistors - enough for about 100 processors comparable to the I-486 or Motorola 68040.

Memory speeds, rather than processor speed, may become the driving limit on performance growth. They have been static at about 1 - 10 nanoseconds (billionths of a second) for several years and are likely to remain so until a new, cheap memory technology comes along.
Figure 5a: MEMORY IC PRICE TRENDS

Figure 5b: MICROPROCESSOR SPEED TRENDS

10-FOLD PER DECADE
CLOCK RATE INCREASE
What will microprocessor ICs be like after 2001? With chips all costing about the same, how should the area on their silicon wafers be used? The most effective use of 'real estate' on the high density chips will increasingly be to provide a diversity of devices rather than one single kind of device; for example, a chip that can support 4 gigabits of DRAM might instead provide 1 gigabit of DRAM, together with several CPU's, pipelined devices, satellite DSP's (Digital Signal Processors), and several kinds of interfaces. System builders and programmers will just use the ones they need. Single chip computers will replace single board computers for small systems.

**Figure 5c: MICROPROCESSOR COMPLEXITY TRENDS**

This technology development has sometimes been called the 'mainframe on a chip'. The opportunity within an IC to choose specialized devices tailored for certain tasks rather than general purpose devices will allow impressive performance improvements (e.g., an improvement in the range of 100 - 1000 for a DSP versus a microprocessor on certain calculations). With integrated parallel and pipelined multiprocessor architectures available on single chips, software developers - from operating system to application level - will find themselves challenged to exploit them. The software literature developed for discrete tightly coupled and loosely coupled parallel machines will be an important resource.

The complexity of these chips grows more staggering. Competitiveness in designing, debugging, and manufacturing them will depend ever more sensitively on the possession of sophisticated computer aided design tools ('silicon compilers') that can generate and test chip masks from high level specifications. Reliable chip designs have been beyond the ability of unaided humans for several years.

**2.4. Digital Signal Processors**

Digital Signal Processor (DSP) chips have become the low cost alternative to mainframes and supercomputers for computationally intensive problems. Sometimes called 'number crunching' applications, these are typified by the problems engineers and scientists need to solve as they try to model the real world.
The 'signal processing' applications that motivated DSP development typically pertained to telephony (e.g., for echo and noise suppression) and to related military (e.g., SONAR) applications. DSPs are now mainstay coprocessors also for speech processing, decompression, multimedia image and video processing, and for modeling and simulation as well as for the traditional digital coding and modulation applications.

But the traditional communication applications of DSPs to signal processing and modulation may be the most far-reaching ones after all. DSPs are making reliable digital broadband transmission affordable on the coaxial cable, wireless, and copper media that will be the customer ends of consumer and business "information superhighways". And they support advanced voice processing (e.g. TrueVoice™ and speech recognition) in communications networks and other computing platforms.

DSP microprocessors can be fast because they buy into the RISC (Reduced Instruction Set Computer) philosophy: build processors designed for blinding speed with only a few frequently-used machine instructions in hardware. DSPs are optimized to perform multiply-adds in a single machine cycle - often in floating point rather than integer arithmetic. Performance on other operations - logic functions for example - may be undistinguished. Complex operations are left to software.

For example, contemporary DSP chips are in the 100 - 300 megaflops range. Plug-in "coprocessor accelerator" boards with several DSPs and extra memory are now reasonably priced. DSP’s have begun to be standard appurtenances on "multimedia PC" and workstation motherboards

2.5. Storage Technology

Processor systems will need and can count on dramatic advances in long-term mass storage - magnetic and optical disk technologies. DRAM loses its contents when it is turned off and SRAM (sometimes still anachronistically called 'core') will still be too expensive for permanent mass storage. Multimedia applications, in particular, hoggishly demand low cost storage volume coupled to very fast access speeds.

In the late 1970s, magnetic storage drives ("hard" disks) with, say, 300 megabyte capacity were $20,000 behemoths the size of large washing machines (about $66/megabyte). Since then, they have evolved into miniaturized 2.5 and 3.5 inch drives (Seagate, Toshiba, Quantum, ...). Those in the new tetherless PC's have capacities up to 1200 megabytes for under $1000 - about a dollar per megabyte or a 60-fold price/performance improvement.

Magnetic hard disks will continue improving in density and cost per stored bit. They can currently store at densities between 0.01 and 0.1 gigabits per square inch. Storage at 1 gigabit (billion bits) per square inch was demonstrated in the laboratory four years ago and should be in products before the decade's end. The corresponding capacity for 3.5 inch drives would be well over 10 gigabytes - enough for 20 hours of compressed (1.5 Mbps) video. The upper limit on physical storage density limit set by magnetic domain size exceeds 1000 gigabits/square inch.

Magnetic hard disks will also continue out-performing optical storage (CD-ROM). They read data at 1 - 10 megabits per second and "seek" a recorded track in about 10 milliseconds or less. Optical disks cannot match this speed - their main value lies in the removability of the medium - and they compete with magnetic tape or floppy disk, rather than hard disks. Typical 5 inch (DVI technology) CD-ROM drives (now under $300) hold about 648 megabytes of data and can read data at only 1.2 megabits per second - just fast enough for compressed VCR quality video. They are slow (200 - 350 milliseconds) in seeking out data at random places on the disk, compared to hard drives.

Despite these limits, CD-ROMs have become the entry level medium for multimedia PCs (now a hot-selling consumer product) and workstations, video game decks (such as SEGA), so-called "interactive multiplayers" (e.g., 3DO). Computer and appliance manufacturers are shipping CD-ROM units as standard equipment, and the trend will accelerate as drive prices drop and the published multimedia literature continues to explode.

Portable PCs are successfully using miniaturized "hard" disks, despite the traditional high power consumption of rotating devices. Some are on removable "PCMCIA" cards. Power-saving chip technology is making tetherless operation more practical.
So called "flash memory" offers solid-state, non-volatile storage, low power consumption, and faster speed than hard disc (under 1 millisecond access). Although flash memory is available today, the cost (about $30 per megabyte) is comparable to that of RAM, and will remain much higher than magnetic disc for the foreseeable future.

2.6. Desktop Computer System Performance

By the end of the decade, the most capable desktop systems will approach and surpass the computer processing power and storage of all but the largest of today's mainframes and 'super minis'. Figures 6 and 7 are independent views of this trend. Both show the PC and workstation systems approaching the 500 - 1000 mips range toward the end of the decade, while the older minicomputer and mainframe technologies are overrun. The large systems that are needed will not stagnate in throughput, but will also incorporate the new microprocessor technology.

Much of the embedded base of desktop systems bought during the early and mid-90's will remain in place and be upgraded. These will serve for several years as the most common CPE (customer premise equipment) platforms that connect to advanced communications services.

Are the centralized computing applications on mainframes going to vanish? Many mainframe applications are migrating now to local area networks linking desktops and storage concentrations (client/server systems) and may also become distributed over wide area networks as the connecting communications become cheaper and more transparent. Some database applications cannot be readily distributed over networks, especially those that allocate pools of resources (like reservations or inventory control) among users. Supercomputing applications are another preserve for large-scale central processors.

Figure 6: COMPUTER SYSTEMS PERFORMANCE
2.7. Display Technology

Multimedia applications require good graphics rendition and resolution to be worth using.

CRTs (Cathode Ray Tubes) still dominate today's display market with the exception of portable PCs. Solid state LCD's (liquid crystal displays) will make significant inroads against CRTs in displays by the decade's end, becoming standard (circa 1997) for PC screens up to about 12 inches. The comparatively slow speed of today's low cost LCDs will be improved and LCDs will support color motion video at popular (NTSC, super VGA) resolutions and reasonable cost.

Large-screen monitors (over 25 inches) are needed to fully exploit multimedia (multiple window GUIs, simulations, ...) and to bring a feeling of "telepresence" to videotelephony. But large CRTs have unacceptable 'footprints" for most business users - they take up too much desk space. Large flat panels (above about 25 inches) can be made up by tiling smaller panels, but they will probably remain too expensive for most users for about 10 years. CRT's may remain the lower cost solution (especially for consumer applications) for some years. Projection systems using small flat active matrix LCD panels may be the best route to affordable large screen and HDTV monitors with acceptable footprints. They may also simplify the problem of providing eye contact in videoconferencing.

The increasing menagerie of mobile and wireless computing devices (notebooks, PDA's, laptop PCs, etc.) will continue to depend on fast, low power, low cost flat panel displays. Super-VGA resolution is standard on commodity PCs and is more than adequate for video imagery of (NTSC and VHS) quality. Non-DOS workstations support comparable or higher resolution. Consumer HDTV displays are not likely to make inroads against NTSC until late in the decade, at the earliest.
2.8. Supercomputing and Future Services

By the end of the decade, we will be able to tackle problems of towering computational complexity. For example, U. S. Government initiatives in High Performance Computing and Communication include cracking the human genetic code ("Genome") and advanced weather prediction - problems of heretofore intractable computational complexity.

Increases in the speed of single processors can take us only a fraction of the way to this goal. Until recently, the conventional 'supercomputer' approach predominated, favoring single thread (straight sequential) computation. In addition to high clock rates, high speed sequential processors use "pipelining" to improve throughput in repetitive operations; processing units in a line are assigned sequential steps in a computation, in order. When each one finishes one computation, it passes its results on and accepts the next problem.

Figure 8 represents the widely shared current view that most future progress in raw computing power will be due to parallelism; that is, finding ways to break up problems into independent pieces that are worked on separately and concurrently by many processors up to a point, and then combined, et seq. Not all computing problems are easily divided in this way, making creative software approaches necessary and leaving some problems beyond reach. Fortunately, much of multimedia and visual applications processing is amenable to parallel computation. So also are many database search problems when the physical data storage use parallelism in search and storage organization (e.g., RAID technology).

Figure 8: SUPERCOMPUTER PROGRESS VIA PARALLELISM
Parallelism is finding use everywhere, from single chips to enormous multi-processor arrays. Highly parallel PC attachments with multi-gigaflop capacity are available today. These are currently used as R&D platforms for some of the key future application enablers, such as speech recognition, natural language analysis and synthesis, and image recognition. Future, scaled up platforms of this type will be common for supercomputing applications. Network based servers (adjunct processors) that support high volume communication, database manipulation, and processing services are likely to be parallel supercomputing platforms in order to cope with large numbers of users.

2.9. Software and Database Technology

Software and database tools improved dramatically during the 1980s. Individual programmer productivity improved at a much lower rate than the hardware technologies, but still the contrast over the past 10 - 15 years is enormous when the increased complexity of the tasks is recognized. Steady advances will continue, consistent with the trends below. Along with microelectronics and photonics (fiber and optical processing), software technology is one of the three "long poles" in the modern technology tent, as seen by most observers.

During the 1980s, the software cottage industry matured and turned into a competitive, commodity industry, as high quality mass market software packages emerged and were sold on a large scale. The consolidation of software vendors will continue, as will the trend to standardized, open operating environments. Desktop office systems will continue to be polarized into worlds governed by the de facto Microsoft (Windows), Apple, and UNIX standards.

A rapidly emerging form of software called “groupware” explicitly provides a shared workspace for use in group collaborations - hence it is also called “collaborative workgroup” software (e.g., AT&T WorldWorx™). Groupware is gaining users who are re-engineering business processes and automating their workflows, and will also be used by consumers who are sharing “virtual community” experiences.

In its simplest form, collaborative software may provide voice conversations together with message exchange or sharing of a program running in one participant’s PC. More capable and sophisticated forms add multipoint bridging, high data rates and video telephony. Multimedia desktop collaboration goes beyond audio or video conferencing by the addition of the shared workspace, implemented by a data structure that might reside on desktops, premises-based servers, or in network server complexes accessible to all. Experimental AT&T "Virtual Meeting Services", WorldWorx™ services, Telemedia™ PC software explore these advanced multimedia applications.

Visual programming and representation will flourish, as multimedia image and video, CAD/CAM, and other simulation techniques become ubiquitous,

Object-oriented techniques can improve productivity especially for database applications (e.g. MIS and operational systems) as well as for program development. They make it easier to define reusable, modular, potentially complex data structures and associate them with appropriate short programs that operate on them. The resulting mix of data and program is called an "object". The routine (short program) names may be overloaded - that is, reused for related routines that operate on different data objects but share the same general use (such as add, delete, modify, print ... ). As a result, it becomes easier to write very compact and powerful programs that do whatever is appropriate to data (of widely variable structure) without having to be rewritten for each data structure they operate on. This can reduce the volume of work needed when creating and maintaining programs - most past techniques have spawned enormous numbers of (typically maintenance) programs differing mainly in small details.

Next-generation languages and database management software should support both object orientation and concurrent programming - parallel computing will be coming to prominence with the growing deployment of on-chip and more loosely coupled parallel systems. The best known language systems that address both of these are the C++ language (with extensions) and to a lesser extent the U. S. military's ADA language system. C++ and the O/DJE experimental database (AT&T Bell Laboratories developments) explicitly support object orientation through the notion of a "class", and C-language additions that support concurrent programs have been defined.

Adaptive software and algorithms are another major frontier. The examples range from simple battery life predictors for use on laptop computers to neural networks that learn from examples. So-called user-agent technology ultimately
looks toward adaptive programs that can learn from their users by example or instruction and act on their behalf. Adaptive programs that are done poorly can create user dissatisfaction and anger, as they force users to do things that the inept agent though they intended to do.

Some other active areas will be concurrent and network operating systems, distributed databases, software quality assurance, and methodologies for requirements specification.

2.10. **Summary: Applications Impacts**

Figure 9 summarizes many of the trends discussed so far. The added computer processing and storage capability will make computers more usable (voice and visual interactions, ...) and adaptable to their human masters. Applications will grow rapidly in complexity (serving human factors), hungrily using up the new-found IC component density to provide memory for the 'ease of use' applications as well as raw speed.

Software will exploit the rich new hardware resources. It can become cheaper to develop by using traditionally uneconomic programming approaches such as higher level languages and prodigal memory and mass storage use, by substituting brute force computation for subtle algorithms, and by using object-oriented discipline. Software will also get better, improving human factors through the use of luxuries such as image, motion video, speech recognition. Both of these directions can be clearly seen in the latest PC applications.

The improved life style and ease of use built into new applications will raise customers’ expectations for distributed, communications-intensive activities and accelerate growth in the demand for broadband and multimedia communications services.

*Figure 9: APPLICATIONS IMPACT OF SILICON IC & STORAGE ADVANCES (TO 2000+)*

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<td>VASTLY MORE POWERFUL DESKTOP AND MOBILE SYSTEMS</td>
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<tr>
<td>10X FOLD CLOCK SPEED INCREASE</td>
<td>FASTER AND CHEAPER PROCESSING &amp; MEMORY ACCESS</td>
<td>GREATLY REDUCED COST PER UNIT PROCESSING CAPACITY</td>
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<td>3.3V (OLD DRAM) TO 1.8V (SRAM) PRICE/BIT DECREASE</td>
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3. **Broadband Networking**

Broadband networking technology is the second driver of the IT revolution. It will continue to grow in power by several orders of magnitude during the rest of this century.

Digital transmission technology is undergoing a revolution comparable to that in computing. As digital electronics technology penetrates further into communication switches, line conditioners (signal processors), and other devices become computer-like. But another distinct enabler is a revolution in optical fiber and optical components themselves that parallels that in silicon electronics. The cost of installing broadband communication systems is becoming scarcely higher than the cost of putting in limited-capacity wires.

The new broadband systems are sometimes called the “information superhighway” - eventually serving large businesses, consumers, and small business locations alike. As communications services become cheaper per bit, we will see wide-scale adoption of bandwidth-hungry multimedia technologies that make liberal use of imaging and video. The transmission technologies affect local access and wide area networks, customer premise and home communications, business and entertainment applications. “Networked multimedia computing” would be a good name for the new paradigm.

This does not mean that communication is on the verge of becoming free: the major costs lie outside transmission - in access, installation cost, administration, billing, etc. But instead communication costs may come to depend much more weakly on the traditional distance and bandwidth measures. A future connection may cost much the same as it does today but be more powerful and flexible.

3.1. **Lightwave Transmission**

Communication systems that use transmission through glass fibers appeared in the 1970s. Capacities increased during the 1980s and long-haul transmission is now carried almost universally by optical fiber. As fiber systems appear, they replace analog lines with digital ones, increasing the clarity of voice conversations and making data communication easier to implement.

3.1.1. **Bandwidth Capacity**

Laboratory measures of single fiber bandwidth have been doubling each year for the past two decades. Research systems now exceed the (AT&T Bell Labs) transmission record of 32 gigabits per second over a 90 kilometer optical fiber. That figure of merit - 2.9 terabit-kilometers per second - set a new world's record at the time. This corresponds to half a million digital voice channels on one fiber. In order to transmit this fast, it was necessary to generate special short duration pulses called "solitons" that retain their shape over long distances. Ordinarily, the light pulses in fiber systems spread out due to dispersion - some portions travel faster than others and cause interference between pulses when the transmission distance becomes long enough.

The key technologies for lightwave fiber progress are Erbium Doped Fiber Amplifiers and Wavelength Division Multiplexing. Until now, most progress has been due to the invention and manufacture of better miniature lasers (laser diodes) that have been able to produce shorter and shorter light pulses down to the order of a nanosecond (1 billionth of a second). Further improvements in this direction may be difficult. The capacity-distance curve (see Figure 10) flattened accordingly in the late 1980’s, but reverted to its annual doubling with the advent of optical amplifiers.
3.1.2. Wavelength Division Multiplexing (WDM)

WDM (or equivalently FDM for Frequency Division Multiplexing) is identical in principle to the way many television channels are carried simultaneously on CATV systems, except that different laser frequencies (colors) are used instead of different radio frequencies. It potentially can put up to 1000 channels with 1 - 10 Gbps each on a single fiber - that is, the potential bandwidth on a single fiber is in the range 1 - 10 terabits per second. A terabit is 1000 gigabits or 1 million megabits.

Advances in Photonic Integrated Circuit (PIC) technology are making increasingly more capable WDM systems commercially feasible. PICs replace individually aligned connections with lithographically produced waveguides on-chip and offer dramatically reduced component size, cost, and component robustness. The most promising laser wavelengths are in the range near 1.55 microns where the fiber absorption is at a minimum. Early WDM systems use miniature fixed frequency lasers and filters to generate and separate the channels. Advanced systems that support more channels will use tunable lasers and will separate channels by coherent detection, based on the heterodyne technique long used in radio receivers. PIC technology also promises a full range of IC-based couplers and interconnection devices for data on fibers.

3.1.3. Optoelectronic ICs

Photonics technology may also improve computing systems in general, where optoelectronic ICs (chips that integrate electronics with on-board waveguides, lasers and photodetectors) may relieve interconnect problems between ICs. Replacing pinouts and rigid buss structures with fiber to the chip can free equipment from many structural and shape constraints.
3.1.4. Optical Amplifiers

The invention of photonic amplifiers (called Erbium Doped Fiber Amplifiers, or EDFA's for short) is having a large impact on fiber transmission systems' economy. Until these amplifiers appeared, it was necessary to install electronic regenerator sites at about 25 to 50 mile intervals along fiber routes. Whenever light pulses in a fiber become weakened by losses, regenerators turn them into electronic signals and recreate the optical pulses at higher intensity. Regenerators are complex and expensive to install and maintain, especially in transoceanic cables; EDFA's greatly extend the distance between them.

Optical amplifiers compensate for the intensity losses in fibers "transparently": they boost the optical signal fed to them independently of the kind of modulation (digital or analog) and data rate used. For example, they work equally well for digital or analog signals. They are reasonably linear across the range of wavelengths to be used with WDM, improving its economics for long-haul routes - otherwise, repeater complexity would be proportional to the number of channels carried.

Amplifier technology is based on research (much of it at AT&T Bell Labs) that discovered how to make short Erbium-doped glass fibers act as lasers in the 1.5 micron wavelength band where the glass fibers used in transmission systems are least absorbing. The amplifiers are powered by breakthrough laser diodes that pump electrons to long-lived energy states using light with either 0.98 or 1.48 micron wavelengths. Incoming light pulses carrying information are amplified by 'stimulated emission' at their own frequency as they pass through the device.

Optical amplifiers may be as important for optical systems as the triode amplifier tube was to radio in the early 20'th century. The absence of an optical amplifier until recently made it difficult (and expensive) to broadcast information to multiple fiber routes. As optical amplifiers (and WDM) become cheaper, economics may favor fiber-based common-bus entertainment and communications networks, for example.

3.1.5. Lightwave Transmission System Capability

Practical fiber transmission system bandwidth has been increasing by approximately 50% per year since 1980 (see Figure 11). The generation of long-haul systems put into service over the past few years typically carries about 1.7 to 3.4 Gbps (gigabits per second). As one might expect, these are still too expensive for even big companies to own; leading-edge customers typically can afford to purchase services giving them about 1% of the full optical transmission capacity.

In new and upgraded long-haul systems, the SONET (OC-48) 2.5 gigabit per second line rate is becoming the standard channel size, with customer access 'pipe' sizes - up to about 155 Mbps - multiplexed together to fill OC-48 channels. Individual fibers can carry much more bandwidth than 2.5 Gbps and will do so by multiplexing several OC-48 channels of this size in time or frequency.

Long-haul systems with 4 - 8 SONET/SDH channels (10 - 20 Gbps) are going into commercial field service, many of them as upgrades to fiber already in place. For example, an undersea commercial system using EDFA's and WDM recently demonstrated operation at 10 Gbps. Local service providers (LECs, CATV systems, ...) can upgrade much existing fiber to lower access costs and support multimedia for businesses and loop subscribers.

Soon after 2000, it should be possible to install systems carrying 40 - 160 such 2.5 Gbps channels per fiber, bringing operational fiber capacity to the 100 - 400 Gbps range.

3.2. Advanced Coding and Modulation Technology

Advanced methods for encoding digital data have become practical and offer dramatic improvements in the usability of coaxial cables and twisted pairs for broadband (multimedia) services. Figure 12 shows some practical capabilities
and applications. It’s important to distinguish coding and modulation from compression - compression reduces the size of a bit stream, while coding and modulation are techniques for rendering a bit stream of some fixed size into electrical, microwave, optical, infra-red, or other signals on some transmission medium (copper wire, radio, optical fiber, ...).

![Figure 11: MAXIMUM SPEED OF COMMERCIAL FIBER SYSTEMS.](image)

The next generation of Digital Subscriber Loop technology (see HDSL and ADSL below) will encode bit streams with high spectrum efficiency. So-called Quadrature Amplitude Modulations (exemplified by AT&T Paradyne’s VideoSpan™-Plus technology) are the likely schemes of choice. For example, about 7.5 bits per Hertz is achievable on 12 - 18 kilofoot unloaded twisted pair loops, packing 1.5 megabits into about a 0.2 Megahertz frequency slice. Shorter loops can have increased channel capacity by using higher frequencies, by coding more bits per Hertz, or both.

Passband modulations combine several channels on a single transmission line (frequency division multiplexing). On twisted copper pairs, the lowest frequency channel can be left available to POTS or ISDN BRI while higher frequency channels carry multimedia/video services. This would maintain “spectrum compatibility” with embedded base service and equipment on telephone loop and PBX/LAN circuits.

### 3.2.1. Transmission on CATV Microwave Systems

The same new modulation technologies are applicable to CATV systems, which already have enormous capability to bring wideband and possibly broadband services to loop customers. This is the source of the “500 channels” foreseen on upgraded cable systems, which are the most likely consumer end of the “information superhighways”.

Experts foresee an overall transmission rate of 20 - 40 Mbps per 6 Megahertz cable channel: the equivalent of about 13 - 25 VCR-quality compressed video streams modulated onto what was only one analog TV channel.
Fewer subchannels (say 3 - 5 per 6 Megahertz slot) would be available when full broadcast video quality is needed. A converted CATV system might have over 40 channels above 550 MHz available for digital services, yielding about 120 - 200 one-way high quality video links, or 520 - 1000 VCR-quality video links at 1.5Mbps. The common bus CATV structure forces users to share and contend for these privately assigned connections.

3.2.2. Transmission on Twisted Pairs: ADSL, HDSL, & Premises LANs

The newly affordable signal processing technologies also allow in-place twisted pairs to carry wideband service (up to several megabits per second) over local telephone loops. This can address the "last mile problem" for customers not served by fiber or microwave coaxial cable. True broadband service (over 100 megabits per second) is feasible over the short distances inside existing office complexes, possibly reusing existing data or PBX lines if the wiring quality is high.

The major new investment needed to upgrade speeds is in signal processor line cards. Copper pairs (of reasonable quality) can be retrofit selectively - one pair at a time if need be - allowing customers and providers to match their rate of investment to actual demand.

Products using this technology are becoming progressively more attractive in price - typically below $1000 per line with the prospect of chipsets priced below $100 per line within 2 - 3 years.

- HDSL (high bit rate digital subscriber line) originated with business services in mind, as an answer to the need for easier and cheaper T1 operations.
Technology Enablers and Impacts

- ADSL (asymmetrical digital subscriber line) technology, is applicable to consumer entertainment multimedia for residences or small businesses. It would provide one way channels at T1 speeds or higher into homes and businesses at distances up to about 18,000 feet along with narrow-band signaling uplinks. It would also allow voice service on the same line without disruption and possibly low resolution 384 Kb/sec ("H0") videotelephony as well.

- New LAN standards (e.g., CDDI and IEEE 802.9) for unshielded twisted pairs in office buildings can use the same technology to reach data rates of about 155 Megabits/second for distances up to about 300 feet. Almost all office building wiring spans are shorter than this. Low cost broadband to the desk on an in-place infrastructure directly complements the new ATM LANs and will powerfully accelerate conversion to networked computing as the standard architecture.

3.3. Broadband Migration

Shortly after 2001, broadband services will be available throughout much of the communications infrastructure. They will be an integral part of most business operations, carrying heavy loads of image and multimedia communication traffic. Broadband services are those that allow transmission speeds ranging from T3 (45 Mbps) upward. Wideband services have bandwidths in the T1 range (about 1.5 Mbps).

The greatest driver for business broadband demand is the proliferation of Local Area Networks (LANs): as of the mid-1990s, most business computers - including desktops - not currently on some kind of LAN soon will be. These limited-reach networks will foster the development of embryonic broadband applications (multimedia conferencing, for example). Other sources of business broadband demand are the growing popularity of computer imaging applications, distributed processing and data bases, and multimedia collaboration/conferencing over network facilities.

Consumer demand for broadband will stem from interactive multimedia-video entertainment, delivered through two way access networks built by CATV providers and local telephone companies. The same access networks will have to carry traffic for the burgeoning business “remote worker” segment, that includes telecommuters, small commercial sites, and mobile users seeking high speed data and eventually multimedia-video parity with colleagues connected to premise LAN systems.

Broadband communications toward the end of the decade is likely to be based on Synchronous Optical Networking (SONET), Broadband ISDN (B-ISDN), and Asynchronous Transfer Mode (ATM) fast packet switching (Figure 13). Local broadband loops will use at least two types of Fiber/Coax systems. Longer term, short range wireless broadband access systems may be feasible, using for example 28 Gigahertz technology. A number of digital satellite systems will be in place, suitable for broadcasting but with at least some two-way interactive capacity. All of these might carry data as ATM packets on a subset of their channels.

3.3.1. Impact of LANs

LAN bridging is an early application of broadband services. Speeds have been increasing at about 28% per year, moving from the 10 Mbps range during the past decade to the 150 Mbps (SONET) range in the 1990s, and on to optical fiber LANs and MANs (Metropolitan Area Networks) with gigabit per second capacity.

The earliest LANs appeared in the mid-1970s. Since then, the bandwidth that major businesses find affordable for interconnecting LANs (about 1% of long-haul fiber bandwidth) has trailed the capacities of popular LANs themselves, creating a bottleneck. In the near term, private line services such as DS-3 (45 Mbps) will increase but over the longer term leased line service will lack flexibility and cost-effectiveness.

Fortunately, long-haul transmission speeds have been increasing faster than LAN speeds. By the late-1990s and thereafter, leading edge customers will be able to afford long-haul transmission that competes on speed with the LANs then in use. Business premise boundaries will begin to vanish as the public network changes from a bottleneck to an enabler.
3.3.2. **SONET (Synchronous Optical Networking)**

SONET is an emerging industry standard that was developed primarily for telephone carriers to use in specifying the optical transmission facilities that they procure. However, as fiber migrates to the local loop and becomes more prevalent as a premises transport medium, SONET will increasingly become the standard for end-user optical communications. The SONET standard defines nested optical channels from OC-1 (Optical Carrier - 1) at 51.88 megabits per second through OC-48 at 2.488 gigabits per second.

3.3.3. **Switching Alternatives**

Today's networks transmit information as optical pulses over glass fibers. The fiber-borne bit streams that converge at a switch have to be converted to electronic form to be switched and then converted back again when they emerge.

Circuit switching and packet switching are the two main technology approaches. Current large switches are almost always electronic digital circuit switches. They expect the incoming signal to represent bits of data flowing in at a known rate and they switch each input bit stream from a specific time slot on a given input port to a specific time slot on an output port. The end-to-end path between a pair of incoming and outgoing (glass fiber) lines is maintained as long as the call lasts. It takes a couple of hundred milliseconds to set up and tear down such a circuit. Digital circuit-switch hardware can be built to carry broadband traffic and would do so efficiently when the traffic flows on circuits are reasonably uniform. However, some applications - notably computer-to-computer and image communications - generate very uneven flows of information: they are 'bursty'. This leaves a switched circuit idle most of the time. Network services that accommodate bursty traffic more efficiently can reduce customers' communication expenses.
Packet switching is expressly designed for bursty communications. People or computers 'mail' little packets of information to each other. Each packet has a header that contains its origin, destination, and routing information, and possibly also some indication of its priority. Each switch node that the packet passes through must interpret and act on the header information.

Packet switching automatically supplies "bandwidth on demand": when no packet is sent, no bandwidth is used and no charges result. It also naturally copes with send and receive rates that are mismatched to each other - at least for short periods of time. The down side of traditional X.25 packet switching technology is its very high overhead, designed to accommodate transmission on unreliable facilities. For example, each packet's data integrity may be checked at each node it passes through. Despite this, packets are occasionally lost or damaged and must then be re-transmitted. The delay until a given packet arrives can be unpredictable and variable, making it necessary to provide a way to re-order packets that arrive out of time order.

### 3.3.4. Frame Relay

Frame Relay (FR) is a popular "fast packet" switched service, available now and growing rapidly. Services currently offer wideband (T1 - 1.544 Mbps) rates and are being extended to a broadband (45 - 50 Mbps) service. Like ATM (see below), it capitalizes on the reliability of modern transmission to lighten the protocol processing overhead.

Frame Relay uses a variable rather than fixed packet length (cell size) and also dispenses with error correction at intermediate nodes - lost or damaged frames can be detected at the destination and re-transmitted. It is a good near-term choice for interconnecting computers and LANs that produce bursty, moderate bandwidth traffic for data and image transmission. It would not be a good solution for multimedia traffic, which might combine a bursty, variable-bandwidth data component (suitable for FR) with less bursty bandwidth needs of voice and video traffic (referred to as 'isochronous' traffic - see below and also the Multimedia section).

### 3.3.5. Broadband ISDN

Broadband ISDN (B-ISDN) refers to an add-on ISDN standard being developed by CCITT. B-ISDN networks will provide switching and transport services for SONET line speeds. The basic B-ISDN access speed will be the SONET OC-3 rate of 155 megabits per second, with access rates up to 622 megabits per second under discussion.

B-ISDN is intended to serve real-time broadband applications such as voice and video as well as data services. Service offerings began in the mid-90s with Permanent Virtual Circuits, and will culminate with the introduction of Switched Virtual Circuits and multipoint standards in the late 1990's. Advanced multimedia services are expected to require B-ISDN inasmuch as it will support both connection-oriented (same route followed by all packets) and connectionless (routing independent for each packet in a call) services.

### 3.3.6. B-ISDN versus SMDS

SMDS (Switched Multi-Megabit Data Service) provides connectionless data transport and, as with Frame Relay, is specifically targeted for LAN interconnection: it does not guarantee to handle real-time traffic like voice and video well. This makes it relatively easy for SMDS to resolve issues like flow and congestion control, high-speed transport protocols, self-healing techniques and network management, with much progress already made. As with B-ISDN, SMDS offers fixed-size cell relay services but uses different cell structures and header information.

SMDS speeds are not restricted to SONET rates but include DS1 and DS3 as well. It appears that SMDS will require some time to evolve into truly broadband services even for data applications. Even so, it is necessary to resolve issues analogous to those for ATM switch technology before broadband SMDS can be widely implemented.
One should foresee a market progression of transitional fast packet service offerings (Frame Relay, SMDS) terminating with B-ISDN (ATM).

### 3.3.7. ATM (Asynchronous Transfer Mode) Cell Relay

ATM is a fast packet switching (also known as cell relay) technology. Like Frame Relay it eliminates much of the overhead that is customarily part of packet switching (e.g. under X.25) and it demands in return highly error-free transmission. Unlike older packet technologies (X.25, SMDS, Frame Relay) it supports connection-oriented as well as connectionless transmission, providing the isochronous (jitter-free) rendition needed for real-time video and packetized voice. The typical access rate for large users will be 155 Mbps, with higher speeds available, and with slower speeds deployed also to spread use of the packet format and signal protocols as an end-to-end standard.

ATM service implementations break messages into **fixed length** cells of 53 bytes (octets) each, of which a 48 byte payload contains message data and the remaining 5 bytes contain protocol control and addressing information. The switching technique involved in handling these self-routing cells is called 'cell relay'.

Many interactions between broadband users can be compared to making a very brief phone call at an unpredictable time and data rate. Computer-to-computer data exchanges and fast still-frame imaging (including FAX) follow this pattern. With circuit switched transport there is significant waste of capacity and increased expense. ATM provides bandwidth on demand within the main trunk routes of a network by intermixing packets that belong to different virtual circuits (in effect statistically multiplexing them).

ATM is designed to carry voice and video (sometimes called 'real-time' or 'isochronous') traffic as well as bursty data and image traffic. It is intended for general purpose use with smooth, un-delayed handling of both real-time and bursty traffic. ATM's great virtue for these applications is the simplicity with which it intermixes different kinds of traffic. ATM switches must manage traffic queues creatively to meet these performance criteria.

### 3.3.8. ATM Architectures and Issues

Most industry experts favor ATM as the B-ISDN standard that will support all broadband services and be especially efficient for bursty broadband applications.

As non-bursty broadband applications become common they may present throughput burdens to ATM switches. For example, video components of multimedia would be appropriate for circuit switched environments, although ATM is the assumed switched video services transmission mode. ATM proponents are confident that they can reliably deliver video with at worst imperceptible variance ('jitter') in the packets' delivery rate. However, it is possible that the broadband network architecture will remain a hybrid of fast packet and circuit technologies - especially for switched connections above 155 - 600 Mbps.

Semiconductor memory speeds may limit the growth of ATM network switches: they have remained fixed in the 10 nanosecond range for several years and are likely to remain there unless a cheap, new memory technology comes along. The bottleneck may force designers to adopt complex parallel architectures to expand ATM switch throughputs above about 100 Gbps (adequate for the early years of deployment).

The scaleable architecture for large commercial ATM switches is a significant technical challenge. An ATM switch for use in large centralized locations must be capable of switching about 1 Tbps (1 terabit per second, or 1000 gigabits per second), assuming 100,000 subscribers each having an access channel of 150 Mbps and 10:1 concentration level. Throughput of 1 Tbps is yet to be realized in commercial ATM technology. Other issues, such as flow and congestion control, high-speed transport protocols, self-healing techniques and network management, await resolution before large ATM switches are widely deployed late in this decade. ATM performance for isochronous multimedia traffic under heavy loads remains a key technical item, but there is no reason to question ATM's adequacy unless systems are overloaded because of undercapacity.
3.3.9. **ATM Switching**

Despite these reservations, ATMs advantages will make it the single, simplifying switch technology from desk to desk through all intermediate networks, with integration of voice, video, data, and image media components. It is likely to displace circuit switched and contention LAN technologies for customer premise LANs and other communication gear. In the public networks, ATM and SONET are the assumed technical underpinnings for Broadband ISDN service. The simplicity of ATM will facilitate wide use of multimedia services.

Most electronic switches developed in the near future will be fast packet ATM switches. ATM technology will continue to advance, benefiting from ongoing cost/performance gains in Silicon IC electronics and from declining costs of parallel computing architectures. In other words, ATM benefits from the same trends that are making multimedia-capable workstations affordable. Steep memory (DRAM and SRAM) price declines will bring down the cost of buffers that must briefly queue packets in ATM switches. ATM switch ICs will grow in size - due to ULSI improvements - beyond the 8x8 through 32x32 range that populates recent designs.

ATM products divide into customer premise and public network markets. The customer premise systems are on the faster development track - essentially because public network applications require much larger throughputs than are needed on customer premises and also because the applicable standards negotiations are more tedious. Current-generation CPE products typically have throughputs in the range 1 - 2 Gbps, while commercial network switches and crossconnects have throughputs in the 20 - 100 Gbps range. Network management problems for customer premises are simpler than those for public networks, allowing faster development and more simplistic architectures to succeed for CPE.

3.3.10. **Crossconnects**

Photonic (Optical) switching is a potential next advance in switch technology. Fully photonic switching would be truly transparent; that is, the switching and transmission systems don't need to care about the form or content of the signal placed on a fiber. The senders and receivers of messages have the freedom to make their own choices, and the responsibility to make the choices compatible.

Photonic switching may become competitive with electronic switching technology (e.g. ATM) for very high speed crossconnects that do bulk point-to-point switching of SONET channels. Electronic crossconnects using ATM would have to be able to keep up with the new SONET line rates. The processors and memory devices used, and the crossconnect structure, need extraordinary speed, compared to those in most computer processing and packet switching applications.

3.3.11. **Internet Evolution and Cyberspace**

The U. S. Federal Government has historically been an active leader in data networking. ARPANET emerged in the 1960s, pioneering packet switching technology and new protocols (TCP/IP). It was the earliest packet WAN (Wide Area Network). The Internet is its successor, linking over 45,000 regional networks together in a loose, primarily government funded low speed backbone for data traffic - a "network of networks".

Internet has been growing at 10% - 15% per month (one year doubling time). It now connects over 4.9 million host computers (many more users) throughout over 60 countries. Most Internet activity has been academic & government generated, augmented by a recent explosion in Internet gateway services and commercial offerings on the Net itself. The traffic has principally been low bandwidth, high latency electronic mail, file transfers, access to mundane and exotic electronic bulletin boards. More recently, traffic has begun to include more large data objects, including imagery, and real time applications from voice to video. The protocols eschew central control, as do the applications.
The Internet has acquired media-chic as the original (and only) true “cyberspace”. Magazines (e.g., Wired) dote on it as an electronic realm of idealized laissez-faire democracy, counter-cultural rectitude and honor, and new-age style packaged with free (if slow) transport.

Given the rapid growth and lack of ordered scaling in Internet, it is not clear how well this “network of networks” will accommodate the expected large growth in commercial and amateur traffic. The advent of primitive multimedia applications, (viz., the popular “Home pages” on the “World Wide Web”) will exacerbate slow response that has frustrated users for a long time and forced them to take a relaxed view of interactivity. Most commercial Internet applications are experiments, and they will very likely migrate to commercial environments designed to accommodate them with improved performance.

Current fast packet services (Frame Relay, SMDS, ATM PVCs) can create interim infrastructure for additional higher-speed Internet-working. The coming B-ISDN broadband network (switched ATM fast packet & SONET interfaces) can improve Internet-working of high-performance computer networks, but many protocol issues remain to be resolved.

The Internet is not (at least not yet) the “information superhighway”. That title - to be held by the more plebian CATV systems and business long distance networks - implies the ability to handle multimedia traffic isochronously, and will be elusive for Internet, given the autonomous control philosophy.

The NREN (National Research and Education Network) is intended to extend Internet to gigabit per second interconnection of superfast computers and high speed LANs. The HPCC (High Performance Computing and Communication) program is sponsored by DARPA, NSF, DOE, and some other Federal agencies. Vice President Gore and now House Speaker Gingrich are its champions.

The HPCC program is driven by the recognition that unprecedented computational power - networked - is needed to solve the ‘grand challenge’ problems. The target capacity for the NREN is 3 Gbps by 1996, with 1 Gbps delivered throughput. These seem like modest objectives. It will be interesting to see whether NREN or commercial B-ISDN implementations appear first with capacity in this range.

### 3.4. Summary: Applications Impacts for Businesses

Figure 14 steps through many of the trends discussed in the section above - as applied to large business enterprises in the late 1990s. The new reality on and off premises supports networked multimedia computing that is no longer constrained by premises boundaries.

### 4. Wireless and Personal Communication Technology

Wireless communication systems of many types will become ubiquitous during the next several years, driven by dramatic increases in the portion of the radio spectrum made available to mobile telecommunications and the growing diversity and sophistication of cheap customer equipment. Business and personal voice and data communications will be integrated for mobile workers and consumers via the extensive deployment of wireless laptop PCs, PDAs, Cellular and PCS devices, and the like. In homes and offices, tetherless devices will proliferate as well.

Perhaps the most interesting technology developments affect cellular telephony, where several developments will dramatically expand the available bandwidth, and in wireless PBX’s or LANs for indoor use, which will free conversations and workstation activity from deskbound limits. Wireless technology promises cost-efficient access to widely dispersed homes and small businesses, bypassing the conventional access systems owned by TelCos and CATV companies, for narrowband and possibly wideband applications.
4.1. Cellular Channel Density Explosion

The density of cellular channels available will explode dramatically over the next several years - potentially by a factor exceeding 1000 in some areas - as the result of three converging trends:

- **Frequency Reallocation:** Cellular telephony in the U.S. is currently restricted to two broadcast bands in the 824 - 849 and 869 - 894 megahertz ranges. These are divided into 7 groups, one of which is assigned to a hexagonal area (a cell), with the remaining 6 groups assigned to nearest neighbor cells to prevent interference. This system makes only 420 channels available, or about 60 per cell.

As anticipated, the FCC has recently opened a frequency swatch near 2 gigahertz to be used by "emerging technologies". PCN systems are the beneficiaries. The intent was to make available about 200 megahertz - about four times the amount originally set aside for cellular services in the 1970's. This was made necessary by increasing demand and a segmentation of markets served by wireless communications. The recent (1995) auction of PCN licenses drew participation from TelCo's, Interexchange companies such as AT&T, MSO's (cable providers), and entrepreneurs who see growing willingness to pay for mobile access for voice and data.

- **Digital Conversion and Multiple Access:** The current cellular radio system in North America is analog. A proposed new North American standard called IS-54 would convert to digital modulation, alter the cell pattern to a higher reuse factor (say, 4 rather than 7 frequency groups), and pack several circuits into each existing 30 Kilo hertz channel. Many proponents favor spread spectrum (code division multiple access = CDMA) over time or frequency division techniques for improving the utilization of existing bandwidth. The digital trend will prevail in cellular systems by mid-decade. Experts estimate that these measures in combination will increase capacity by about a factor of 5.
**Microcells:** Most of the projected gain in the number of cellular channels is attributable to new technology applied to the cell site transceivers. Today's urban cells typically have a radius of about 1 to 1.5 miles served by an antenna about 150 feet high. With microcells, the cell radius can be reduced to under 1000 feet (in some cases to 250 feet) using 30 foot antenna elevations. The increase in channel density that is actually realized using microcells depends on economic choices. The densest microcell pattern - in a downtown financial district for instance - might increase the local channel density by a factor up to about 1000. Experts estimate an average channel density gain for an urban area of about 60-fold.

Microcells will proliferate in high density urban areas as the cell site costs continue to drop. Larger cells will continue to serve suburban/rural areas where subscriber density is lower. The same miniaturized portable receivers must serve all of the cell implementation schemes.

A full deployment of microcells can also "bypass" the traditional TelCo copper pair networks, avoiding the combinatorially large and expensive "last mile" problem associated with the service drops. Microcell site transceivers can be installed every few blocks on buildings, trees, or poles with connections into non-TelCo central switches via optical fiber links or bi-directional coaxial cable systems. Each home would have a transceiver/controller that connects to conventional copper lines and phones inside the building. Systems of this kind can use cellular or more likely PCS frequencies for voice and low speed data - including cellular packet data (CDPD). Longer term, systems of the same type (sometimes called "wireless cable") but using radar frequencies and technology (LMDS, say 28 - 30 Gigahertz) can support wireless video/multimedia, but with line of sight and range limitations.

### 4.2. Wireless PBXs and LANs

Wireless PBXs or LANs are an extension of cellular technology to the indoor office. Sometimes called Femtocellular PBX or Wireless Centrex, this technology can free office communications from its chains to the desk. Some wireless LANs capable of transmitting 10 megabits per second within a room or building are already available, and wider bandwidth experimental systems exist.

Wireless LAN or Centrex has the very appealing property of allowing the movement of people and their equipment within a building or campus. In effect, employees carry their office telephones with them wherever they go, reducing the logistics associated with personal movement. Some buildings (e.g., those with metallic structure) pose technical challenges to radio propagation. And, issues related to secure communications are often reasons for users concern.

### 4.3. Personal Communication Networks

One of the more exciting developments is the authorization of communications frequencies to support Personal Communications Networks. The FCC has been auctioning the frequency spectrum across the nation to anyone who wishes to bid on the "franchise" of the spectrum. Consortia of wireless providers are affiliating to seamless PCN network services.

The FCC is allowing "Pioneer Preferences" to ensure those providers who have invested in the research and development of the technologies supporting the service to be given the opportunity to compete in this new market. Although not applied to every market, this policy has had the effect of substantially raising the bid price for the spectrum allocations.

Personal communications can be close to a reality by the end of the decade. In the PCN scenario, everyone could have a personal phone number allowing individuals to be reached wherever they might happen to be. Imagine leaving your house, traveling to work by car, moving about all day, and then returning - with all the technology changeovers from system to system accomplished seamlessly. A single transceiver type (and particularly, a single antenna type) would need to serve several wireless systems, since few users will want to carry multiple handsets.
4.4. Standards

Intense standards activity over the next few years will resolve competing schemes and provide interoperability between classes of wireless systems, which include: cellular, PCN/PCS, cordless phones, telepoint (public access), wireless PBX’s, wireless data, and paging, with many hybrids.

4.5. Terminal Evolution and Proliferation

The trends in IC density suggest that the technology of hand-held portable wireless terminal equipment will be able to meet the dramatically expanded complexity of PCN schemes at acceptable cost. Speed requirements are modest, except for signal processing. Electronics technology gains will support the high complexity that will accompany feature diversification and increased functionality for mobile applications.

The PCN vision includes mobile PCs with data and possibly some multimedia capability. By one estimate most PC’s (estimate 90%) will be wireless by 2000. Wireless PC operation puts a premium on power supplies and low power components - especially important for displays.

4.6. Other Wireless Technologies

4.6.1. Low Earth Orbit Satellites (LEOs)

Motorola proposes to orbit 66 communications satellites in low orbits (IRIDIUM), providing truly global wireless coverage. Motorola plans to begin launching in 1996 with a 1998 service turn-on. The telephone switching system would be space-based. Communications would be possible from anywhere to anywhere at any time in any way. The system would receive from and/or place calls to mobile terminals or wired station sets.

The cost of this system is expected to exceed $3.5 Billion, but its proponents believe it can have large commercial appeal due to reduced handset power requirements, universal/global coverage, and high reusability and sharing of infrastructure equipment. Other entrepreneurs (Craig McCaw and Bill Gates) have similarly announced their intention to construct LEO systems (TeleDesic) for the purpose of capturing a share of the very large wireless communications market. TeleDesic may use 28 - 30 gigahertz technology and provide broadband access.

4.6.2. Very Small Aperture Terminals (VSAT)

As a fairly mature technology, VSAT is expanding into different markets. Besides the traditional applications as access for stationary corporate assets (branch offices, retail outlets, etc.) to corporate private networks, this technology is being expanded to mobile assets. Over-the-road trucking has been using this technology to communicate with truckers on the road, outside of the normal coverage of specialized mobile radio. The technology has been attractive because it bypasses the access charges of the Local Exchange Companies. It is used heavily for short transactions such as credit card authorizations.

With new Data Over Voice (also called Simultaneous Voice/Data) services on POTS lines and their liberal tariffs, VSAT may lose popularity over the next few years.
4.6.3. Direct Broadcast Satellite (DBS)

Recently introduced to consumer markets, this technology can have a powerful effect from a purely economic point of view. It offers great economy of scale for delivering broadcast, high quality programming and data (i.e., premium TV channels) at about $8 per house passed. Compared with coaxial cable plants at about $800 per house passed and telephone plant modified to deliver video at $1500 per house passed, this technology has great potential to compete strongly with the wired technologies. The quality of reception is outstanding and the diversity of the programming competes with any cable system. DBS is very well positioned to capture high value video programming delivery and leave the mass market uplink problem to TelCos, MSOs, or PCN providers. Note that DBS can accommodate uplinks also, but the antennas need to be aimed rather precisely at a satellite (typically geosynchronous so that it need not be tracked), and the number of channels available would fall far short of terrestrial systems.

4.7. Wireless Location Systems (GPS)

GPS (Global Positioning System) applications have begun exploding as the receivers decline in price. This system employs signals from a constellation of 23 Department of Defense satellites originally launched to accurately determine mapping coordinates for military personal, equipment and targets in wartime. Its extraordinary success in facilitating troop movements, targeting and navigation in Operation Desert Storm demonstrated a highly reliable system for commercial use. The absolute mapping accuracy allowed for military applications is several meters, world-wide. Civilian accuracy is intentionally degraded to about 10 -20 meters in absolute mapping accuracy. Despite this, civilian users can obtain relative mapping accuracy (say, between an airplane and the runway it’s landing on) to within a meter .

GPS is now being used as the standard in both maritime and aeronautical navigation. Commercial vehicles, and railroads employ it to determine the position of goods in transit. GPS is being used to custom plow large farms, to situate and later locate containers in intermodal shipping yards, to track transportation (bus) and emergency vehicle fleets, to assist hikers in finding trails, and to assist motorists in distress. The conjunction of low cost ubiquitous mobile communications to information about a subscriber’s whereabouts can open a vast opportunity for applications and services.

4.8. Summary

Wireless technology will increasingly un-tether the business professional and consumer, and be useful for bypassing local telephone loop plants. Mobile data with voice will be a powerful combination for a number of business segments. On the consumer side, wireless technologies have lowered the barriers to entry for alternative access providers. These technologies will expand customers’ choices about how and when they will communicate.

5. Compression Technology

Within the next two to three years, low cost, commodity compression/decompression chips (“Codecs”) together with affordable processing and high speed networking will bring down the cost of high quality video and imaging applications. By the 2000+ period multimedia applications can become ubiquitous in business and in consumer sectors.

The key technology advances are the promulgation and acceptance of international CCITT standards for multimedia and their implementation in special purpose integrated circuit chips that are about to become low cost components in workstations and consumer appliances.
A common compression technology will link compact local storage in multimedia business workstations, home or office PC's, and new consumer appliances (e.g., game decks, multiplayers). It will appear in customer equipment (servers, set top boxes, ...) that enables low cost image and video transmission over channels with bandwidths low enough to become commonplace. It will be applied to large multimedia databases hosted in networks, gateway service providers' facilities, enterprise servers, etc.

5.1. Definitions

Many people miss the distinction between compression and coding/modulation technologies:

- **Compression** reduces the size of a digital file or bit stream for efficient storage or transmission. A fixed amount of information is carried by a smaller number of bits - the subject of this discussion. Compression is sometimes referred to (imprecisely) as coding.

- **Coding/Modulation** packs a fixed-size bit stream (compressed or uncompressed as above) into the narrowest possible frequency range for transmission without adversely affecting the error rate. Coding/Modulation coding technology is sometimes also referred to (imprecisely) as compression, but it is a different technology.

Compression reduces a file's size by removing redundant information. Most of the obvious ways of recording images, speech, music, etc. use far more than the number of bits that could suffice if some cleverness were applied. Many standard compression algorithms have been devised over the years and built into devices called "codecs" (coder/decoders).

A compression algorithm is "lossy" if data compressed using it cannot be fully restored to its original state when it is decoded. This is the case when some of the non-redundant data is discarded. The payoff for using lossy codes is their greatly increased compression ratio. Multimedia data are usually intended to impact only the senses and can tolerate some loss of detail. The compression choice depends on a subjective tradeoff between the users' required quality and compression ratio. Digital image and video can be compressed by 50:1 for still color images and up to 1000:1 for color motion video.

Traditional computer files cannot tolerate error and must be processed by "lossless" compression codes (e.g., Lempel-Ziv or Huffman). As a result, they cannot be normally compressed much more than about 50%. The multimedia materials produced by production shops and publishers are often handled as data rather than sensory input to avoid degraded quality - implying lossless compression. Medical imagery is often handled similarly.

5.2. Multimedia Standards

The three most important image/video compression standards (CCITT) are JPEG, MPEG, and H.261 (also called Px64). They are all lossy DCT (Discrete Cosine Transform) techniques. Barring the emergence of a technical breakthrough, DCT algorithms and compression engines will be dominant until the end of the decade:

- **JPEG Algorithm**: A compression technique for high quality, full color **still** (photographic) images. The draft standard was issued in 1989 and was finalized in 1992. The baseline system can produce good quality images in 3 to 6 seconds over 64 Kbps lines.

- **P x 64 Algorithm**: An algorithm (also known as H.261) developed for real-time video compression in two way **video telephony/conferencing**. It compresses motion video into ISDN channels that are multiples of the basic 64 kilobit per second ISDN pipe. P can range from 1 to 24 (U. S.) or 32 (Europe). It covers codecs (coder-decoders) operating from 56 Kbps to 2.048 Mbps. The algorithm uses inter-frame compression (motion compensation), DCT, and Huffman codes. The (CCITT) standard was completed in 1990.
MPEG-I Algorithm: An (ISO) video and audio algorithm suite specifically designed for multimedia entertainment applications and offering functionality similar to that of the DVI (Digital Video Interactive) proprietary algorithm but with better quality. It is focused on bandwidths of 1.5 Mbps, with 1.2 Mbps for video and 256 Kbps for audio. MPEG-I yields image quality better than VHS and attains compression ratios from 10:1 to 50:1. MPEG-II will address bandwidths up to 10 Mbps with better quality video.

5.3. Video Quality Grades

Several video performance grades are defined for telephony/multimedia, and entertainment video including some narrowband, low quality services.

There are, generally speaking, six useful video grades: HDTV quality (at 20 - 600 Mbps, depending on image size and compression selected), broadcast quality (at 2 - 45 Mbps), teleconference and entertainment quality (at 384 Kbps to 1.544 Mbps), low resolution service (at 56 - 128 Kbps), analog videophone quality (at 9.6 - 19.6 Kbps), and finally freeze-frame quality (at 2.4 - 9.6 Kbps).

The best of today's compression techniques can deliver VCR (entertainment) quality video suitable for display on 25 inch screens at a transfer rate of 1.5 megabits per second (equivalent to T1/E1 lines). This appears likely to be the consumer market compromise for CD-ROM and CATV video. It's unrealistic to expect studio quality NTSC video (PCM coded at 90 Mbps) to be compressible below 750 Kbps, independently of the computational power that available. NTSC is American standard for video transmission and TV design - the other important global standards are called PAL and SECAM.

Videoconferencing at 384 Kbps (fractional T1 - sometimes called H0) is currently a popular commercial service and a candidate for garden variety desktop and consumer videotelephony over the next few years. It's about the lowest data rate that produces smooth motion together with convincing detail, although many business users get by with lower rates. Lower resolution and frame rates are often adequate desktop “talking head” collaborations.

Today, by properly combining lossy and lossless compression techniques, we can encode full motion video signals with moderate to high quality for data rates as low as 56 Kbps, but with smaller (about 144 x 176 pixel) picture size. ISDN basic access (BRI) can support three videophone arrangements with up to 112 Kbps video and 16 Kbps audio on its standard two “B” channels of 64 kilobits/second each:

- One B channel: 16 Kbps for audio and 48 Kbps for video
- Two B channels: 64 Kbps for audio and 64 Kbps for video
- Two B channels: 16 Kbps for audio and 112 Kbps for video

The first and third arrangements require 16 Kbps audio codecs. The third option will deliver the best picture quality.

5.4. Image/Video Computation Power

Tremendous signal processing power is required for image/video coding, whose algorithms are about one order of magnitude greater in complexity than those required for audio. Custom IC chips are the obvious computation engines for real-time performance at reasonable cost, with DSP processors an alternative, especially for still-frame imaging. Compression technology price/performance breakthroughs closely track the IC hardware trends discussed above, with some continued improvement in compression algorithms themselves.

The codec functionality that recently resided in $30K - $50K boxes (e.g., from CLI and PictureTel) has migrated to coprocessor boards available for a few hundred dollars, and will migrate further to chipsets below $100 by late 1995 or shortly thereafter. The first major vendor announcement of a fully standards compliant codec chipset was the (3
chip) AT&T AVP1000 chipset (April 1992) that supported all of H.261, JPEG, and MPEG when used with a DSP 5210 on a coprocessor board. Single-chip improvements are now appearing in the marketplace and will be commoditized within the next couple of years.

### 5.5. High Definition TV

High Definition TV (HDTV) is likely to become an affordable option in entertainment and multimedia services markets by the turn of the century. Digital video compression technology has surprised planners by finding a way to compress HDTV into a digital bandwidth of about 20 megabits per second, which can in turn be modulated (3 - 4 bits/Hertz) onto the current 6 megahertz channels used by analog NTSC television for broadcast. Cable transmission channels (also 6 Megahertz) may be able to carry two HDTV channels due to lower noise. Although HDTV and NTSC receivers will not be compatible, the channel compatibility will encourage HDTV acceptance because it will not dislodge established channel assignments and facilities. However, with multimedia compression technology based on NTSC standards (MPEG I, II) and ISDN (Px64) beginning to deploy, HDTV may miss the market.

### 5.6. Audio Compression

As indicated above, audio compression is important for adding image or video sub-bands to channels that were formerly used by audio alone. This makes it necessary to compress the audio component. Another is to improve the quality of rendition - say from speech to high fidelity music - in a channel of fixed data rate.

Audio compression algorithms are maturing. Today, perceived speech quality falls off steeply only below about 16 Kbps, with intelligibility remaining constant down to 4.8 Kbps. By mid-decade, speech quality should remain imperceptibly the same down to about 4.8 Kbps. The impact will be apparent to cellular and digital storage (CD ROM) as well as multimedia applications. The standardization efforts for 16 Kbps audio codecs are about one year behind the video efforts.

### 6. Speech Processing Technology

Voice contact is the traditional communications interface between people. Telephone service during the past century exploited the ease of use, spontaneity, and naturalness of people-to-people voice interaction to become dominant over telegraphy (early data communication with a primitive keyboard). This may happen again, in some sense, as improved speech processing technology makes voice-based interfaces between people and machines accurate enough to be useful and affordable. High quality, real-time applications will become affordable in progressively more ubiquitous products and services, reaching consumer products within several years. Some current consumer products use low cost but rudimentary recognizer chips.

The major kinds of speech applications are speech recognition, speaker identification, speaker verification, speech synthesis, language identification, and language translation. They owe their new-found practicality to low cost signal processors, typically built around DSP integrated circuits. AT&T Bell Labs has intense speech processing and signal processing research programs.

Despite the naturalness of the speech interface, some human factors that restrict the applicability of speech technology include privacy considerations and the need to avoid interfering with other persons at work.

### 6.1. Speech Recognition
Technology Enablers and Impacts

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Bell Laboratories

Speech recognition (sometimes called ASR for Automatic Speech Recognition) is the mechanized ability to correctly identify spoken words. It is extremely computation-intensive, and much more difficult than speaker verification or speech synthesis. Recognition is prerequisite to machine translation.

Recognizer performance has improved impressively over the past several years. Applications in AT&T and other communication networks, workstations, vehicles, and other contexts are beginning to appear and will become commonplace by the year 2000. Some of these will use large vocabularies or be speaker independent, while many others will be useful but much less demanding. The applications currently running use limited vocabularies.

Recognition is accomplished through computerized pattern matching that compares spoken words with stored speech models and selects the best match. Progress comes from improved models and declining costs of brute force computation. Before trying to match a speech template, the system must first decide when a new word has begun - a serious problem since speakers ordinarily slur their words together. The current AT&T recognition technology uses a statistical approach called Hidden Markov Modeling (HMM).

Speaker independent speech recognition works for (virtually) anyone on demand. It is clearly much more difficult and generally useful than speaker dependent recognition, which recognizes words spoken only by specific individuals. Each person who is to be recognized using speaker dependent recognition must generally be known in advance - usually but not always a disadvantage - and the system must be trained to recognize his/her voice uttering a specific set of words. To have speaker independence, word samples are collected from many individuals and incorporated into generalized speech models.

Some of the easiest recognition applications, called ‘command and control’ tasks are typified by menu selection - it is necessary only to spot certain words in a sentence. The vocabularies for these tasks are usually small (less than 100 words). High accuracy (99%) speaker-independent performance can be provided with under 100 Mips processing.

Other important applications include catalog ordering, credit card validation, and digital dialing. These require the ability to recognize connected strings of words or digits. Again, these are generally speaker independent with high string accuracy (typically 98 - 99% on a five digit string). Word spotting is also particularly useful - it picks out key words from among extraneous speech. This overcomes the natural tendency of callers to add a variety of words around the key phrases. Barge-in capability allows a user to speak without waiting for system prompts to finish.

Current (AT&T Bell Labs) laboratory performance - speaker independent - for fluent speech recognizes over 95.5% of words in a 1000 word vocabulary. Forward-looking applications such as voice dictation machines and computer secretarial assistants require continuous word recognition from fluent speech with a large vocabulary. The end of the century should make available continuous recognition with usable accuracy for a vocabulary in the range of 5000 - 20,000 words. About 1000 - 10,000 mips will be needed, distributed over 5 - 50 DSP processors (of year 2000 vintage). Many of these may reside on one chip.

Although desktop and perhaps mobile systems with processing power in this range may be available, they will not yet be ubiquitous and cheap - especially in view of a lingering embedded workstation base. However, even the most ambitious speech applications can become part of the communication network’s routine user interface, supported by powerful adjunct processors, and may become seamlessly available as service offerings.

6.2. Speaker Verification and Identification

Automatic speaker (or talker) verification decides whether an individual who provides a speech sample is the person he/she claims to be. Numerous verification uses are feasible, such as controlling access to premises or preventing fraud in banking and credit transactions. Some of these may be conveniently offered as services delivered through communication networks. Error rates are currently about 1% for previously agreed-on utterances, and about twice that for others. By the end of the decade, error rates can be reduced by at least a factor of 2.
Early systems will verify a speaker's identity by matching a spoken verification phrase with a stored version of that same phrase. Users would be prompted to repeat a sequence of words or numbers. Advanced systems will check identity from a more freely chosen utterance, possibly in context. For example a caller might say, "This is extension 1234, place a collect call to John ..."

Speaker identification answers the question, "Who are you?". It picks a user's identity from a set of possible talkers, based on some utterance. A practical application might be identifying individual family members who share a phone line in order to perform voice command dialing, controlling message access (e.g., "Do I have any messages?"), or supporting home security.

For a large population (e.g., users of a network-based service) speaker identification becomes qualitatively more difficult than verification. It has to select the best match from a large number of stored speaker profiles. This is clearly a difficult, long-term application.

**6.3. Speech Synthesis**

Synthesized speech, also called text-to-speech (TTS) is simply the pronunciation of words by a computer. Although it is readily understandable, it has traditionally had a machine-like sound whose elimination is the object of progress in the field. The primary benefit over recorded speech is that synthesized speech directly converts written text into audible speech. This means that corrections, revisions, and new material are achieved simply by storing new text files in the computer system.

Speech synthesis is already widely used in man-machine dialogs; further progress will make it more natural-sounding over the years. By the late 1990s, speech synthesis systems (using DSP processors) will be able to model personal voice patterns, handle unrestricted text, and possibly emulate a specific person speaking foreign languages realistically.

**6.4. Spoken Language Detection/Translation**

Spoken language detection/translation capabilities become more important with growth in the need for communications and systems with trans-national capabilities.

Language detection is triggered by a short phrase. It may be as simple as the language name in its native tongue. After the language used is identified the session is switched to a menu, a human attendant, voice response system, or translation service based on the appropriate language. If the text being spoken is known, then the speech sample can be relatively short (on the order of ten seconds) and the accuracy can be high. A 90% accuracy might be achieved in identifying one language out of 10 choices by 1996, and out of 20 choices by 1998.

Spoken language translation was once, during the early history of computers, the "holy grail" of machine intelligence. High performance is still elusive and very difficult - effective translation requires near-human linguistic ability and contextual understanding. Capability will be limited to very structured tasks for many years, but useful applications can be found. Limited domain, small vocabulary, language translation has been available in laboratory demonstrations. For example, VEST (Voice English/Spanish Translator) was demonstrated at Expo ’92 in Seville and in later in field trials. It translates short, simple banking and currency transactions. By 2000, capability may improve to medium size vocabularies, still heavily domain-restricted.
7. **Image Recognition Technology**

The most important image recognition capability for IT is the recognition of machine printed or handwritten characters. This is usually done by processing still-frame imagery that has been digitized by a scanning device and stored on a computer system.

OCR (Optical Character Recognition) equipment has been sold commercially since the late 1960s, but the systems have been large and expensive until recently. Accuracy has generally been mediocre, except on special typefonts designed to make machine recognition reliable. High volume OCR machines still generally require racks of dedicated hardware to handle a wide range of fonts.

Advances in OCR technology can make desktop OCR commonplace and network services based on high volume platforms fast and accurate by the late 1990s. Recent research advances include improved algorithmic (rule based) approaches, but neural networks have recently emerged as the best current performers. Neural networks currently have highly accurate performance for both machine fonts and handwritten digits.

The neural nets are built and trained laboriously using software simulators, but once trained they execute with reasonable throughput on desktop DSP coprocessors. Throughput can be accelerated dramatically when part of the neural processing is ported to the custom neural network IC chips that have been fabricated (at AT&T Bell Labs and elsewhere) and have become incorporated into coprocessors. Neural techniques have been fruitful for recognition itself, and also for the computation-intensive pre-process (called segmentation) of finding areas on a noisy page that are rich in textual material. The performance of future recognizers can be improved by using contextual rules (typically application-specific) in conjunction with character-by-character OCR. AT&T Bell Labs has successful research and product realization efforts in this area.

The easier OCR problem - machine printed font recognition - has useful near-term applications, including the automated construction of databases for use in information retrieval applications. Simple OCR, combined with effective segmentation of text from illustrations, can build keyword references and text from printed matter, whose stored bitmap images will then be accessed. Applications to the conversion of books, the assembly of reference hypertexts, maintenance of product selection and ordering systems are near-term possibilities.

OCR of handwritten digits alone can be useful in reading postal zip codes, insurance or tax forms, checks or credit slips, etc. In some cases, redesign of the forms would help and be acceptable. Useful applications could be fielded, conservatively, by mid-decade. Efforts to develop useful performance on handwritten block characters are using contextual clues in address-reading experiments.

Recognition of cursive handwriting is an especially difficult problem because it is so difficult to segment (separate) the letters of the Latin alphabet we use. The successful interpretation of Japanese characters in a pen-based commercial product is attributable to using information about the stroke order gathered at the time of input and to the discreteness of the character set. Evidently, Japanese learn to stroke characters in a reliable, uniform way. Pen-based OCR of block Latin characters has also been demonstrated. Although pen-based OCR has many useful applications, OCR is in general more useful if it does not make the special demand that stroke order be captured from the writer. Some researchers have applied the same (Hidden Markov Model) statistical methods used to separate slurred words in speech to cursive handwriting, with encouraging results.

It may be much easier to verify whether a handwriting sample was written by a particular person - a capability that would be useful, for example, in spotting check forgeries. It's not necessary to actually recognize the letters. Signal processing techniques that look for characteristic patterns (called 'signatures' - not to be confused with handwritten signatures) have been successful in military applications and might succeed here using DSP computation engines.

Recognition of more complex shapes in still frames, real-time analysis of video, machine vision and other forms of advanced image recognition are interesting research projects but will probably not find useful applications deployed on a wide scale until well into the next millennium.
8. Multimedia Systems

A multimedia industry is emerging. The revolutionary technology advances discussed earlier are providing affordable platforms rich in computer processing power, bandwidth, and storage. They are enabling dramatic declines in video and image compression costs, the acceptance of standards, and the production of low cost commodity chipsets and DSPs. These resources will be combined in new ways at low cost, democratizing multimedia-visual applications for business and entertainment.

New desktop processors, digital TV set-top boxes, and many other business and consumer products will be able to support easier to use visual applications at low cost, acquiring throughput and storage capabilities exceeding those of historical mainframes. New, 1996 commodity office PCs will have about 250 MIPS (Intel P6), 64 Megabytes of RAM, and 1 Gbyte of disk. Motherboard DSPs, image/video codecs, and video electronics have become affordable and will soon be standard items. By 2000, commodity PC throughput will reach about 1000 - 2000 MIPS, with comparably expanded storage and memory, and with built-in video capability. Much of the embedded base of desktop systems bought during the early and mid-90’s will remain in place and be upgraded to some level of multimedia-capability.

There are important differences between network and premises (business or home) implementations of multimedia-visual services: the network versions need to be scaleable to larger numbers of users, fully standards-compliant, and able to handle combinations of diverse subscriber equipment. As a result, the CPE (customer premise equipment) versions of some multimedia applications are simpler to build and may appear earlier, but they may not scale well to public networks or set the standards needed to support corporate decentralization/globalization.

Much of the added computing power will be available for making human interactions with machines and communications more closely approximate face to face human conversations. Multimedia-visual (along with speech recognition) user interfaces will greatly improve the naturalness and ease of presenting and accepting information.

8.1. What’s Multimedia?

In everyday life we use all of our senses and inspect many forms of material simultaneously to receive and express information. Why not expect the same from systems we deal with for work and recreation? The combination of different forms of information can have synergy. This notion prompts an intuitive definition of multimedia.

- Multimedia uses several media in conjunction with each other to increase the precision, impact, and completeness of the presentation. It creates new information by juxtaposing data not previously adjacent. People may supply synergy by associating simultaneous views perceived through different senses and faculties.

The term multimedia is often applied, in practice, to almost any combination of text, bitmap imagery, vector graphics, sound, or video, whether or not any synergy between them should be expected, and sometimes when the bandwidth needs are still quite modest. One would like to insist that delivery systems explicitly add some value to the separate contributions, but synergy is admittedly to be found mostly in human user’s associative abilities. As a result, it’s most practical to adopt the somewhat reductionist approach of dealing with multimedia as a basket of technologies, some of which were discussed in earlier sections, together with a set of applications that they serve. Multimedia is also a way of elaborating on demands for easy to use interfaces - adding more types of sensory interaction increases the naturalness as well as the informativeness of encounters.

8.2. Market Segments and Convergences

There is not currently one single multimedia market, but fractionated ones with different histories that happen to be able to use and share technology. At least three historically separate information industries are simultaneously spawning distinct ‘flavors’ of multimedia technology and early applications. Although the basic computing,
communications, and software technologies are converging amongst themselves, market sector distinctions will persist for many years. The platforms, support software, and key applications are developing along similar timetables (driven by affordability changes in the common underlying technologies) but with differences in price and performance sensitivities, and in access to broadband communications:

- The first flavor is that of large business computing and communications, dominated by large business organizations’ needs for teamwork and powerful data manipulation tools. Traditional business computing applications will migrate to multimedia PCs and workstations typically interconnected via a LAN, using local ROM-resident multimedia applications, migrating to networked ones. Desktop activity will increasingly focus on conferencing and workflow automation using PC-telephony integration and groupware, bridged locally on-premises or in the public network.

- The second flavor is that of consumer-sector appliances and entertainment, historically using television, CATV, video game technology. These remain important and grow more intelligent, remaining cheap, ubiquitous and connected to the CATV broadband infrastructure. A consumer PC market of substantial size is likely to form around multimedia PC’s and software designed specifically to be home appliances, beginning with the heavy sales recorded late in 1994. Historically, PCs in the home principally supported work applications. A greatly enlarged CD-ROM repertory of multimedia entertainment and reference works has appeared and will grow. Local applications for both video and PC environments will migrate to interactive video information and telephony services, using competing broadband access systems (upgraded CATV, loop fiber-to-the-curb).

- A third technology flavor is derived from traditional, primarily business telecommunications applications, driven by needs for universality of access from small highly distributed sites, flexible connections and interoperation, in some cases mobility. The customers are small business sites, mobile workers, and those working at home whose historical applications emphasize person to person (originally voice only) plus low speed data encounters. The applications will expand to include multimedia messaging (including FAX) and collaboration, and information retrieval. Connections’ bandwidth may be variable, including wireline, cable, and radio access, but for stationary locations at least there will be demand for parity with large business sites. CATV may be the first broadband option to reach small businesses, using cable modems that interconnect with PC’s. The terminals mix technology from both flavors above. The applications will extensively use network-based services (data and video collaborations, storage, information,...) to make up for lack of premises support. Given large businesses' decentralization trend, this market sector will grow at the expense of the first sector above.

Terminal types for all three technology flavors will diversify for the next several years, while also converging with respect to shared technology. To what extent will today's PC's, telephones, and video gear remain distinguishable as different categories of equipment by the early 2000’s? Certainly much less so than today. Over the very long term (post-2005), the functional differences will blur, with differences measured, perhaps, by speed and capacity measures.

Figures 15 and 16 lay out the major types of large business and consumer multimedia applications on a time line that predicts when they start to be adopted on a significant scale.

8.3. Large Businesses - Multimedia Enablers

Large businesses internal computing environments are evolving into multimedia-friendly ones (Figure 14), driven by the client/server conversion trend, the availability of broadband premise equipment, and affordable workstations that can handle desktop video. They will become true "networked multimedia computing" systems as access networks and WANs offer high speed services (such as ATM/B-ISDN). Companies will be able to adopt multimedia applications on a trial basis without setting up broadband infrastructure costs as barriers to entry.

8.3.1. Client/Server Migration
Technology Enablers and Impacts

Figure 15: Business Multimedia Evolution

Technology Level:
- Local Networked Data & Video
- Networked Interactive Voice/Data/Image
- Virtual Reality

Applications:
- Interactive Authoring
- Document Imaging
- Multimedia Authoring
- Hypertext Creation
- Publishing, Training
- Computer-Aided Design/Engineering
- Simulation/CAD
- Networked/Interactive Voice/Data/Image
- Virtual Reality

Video Component:
- Interactive Video
- Limited to High-End Workstation Users
- Affordable Desktop Video
- Enables Applications
- Higher Resolution Video

Figure 16: Consumer Multimedia Evolution

Technology Level:
- Personal Computer Networked Voice/Data
- Local Networked Interactive Voice/Data/Image
- Networked Interactive Voice/Data/Image
- Virtual Reality

Applications:
- Broadcast/Video/Entertainment
- Video On Demand
- Multimedia Entertainment
- Video on Demand
- Online Services
- Online Catalogs
- Online Services
- Multimedia Kiosks
- Multimedia Access
- Home Telephone
- Consumer Collaboration
- Digital Multimedia Appliances
- Limited Access

Video Component:
- Analog Video
- Multimedia PCs/Games
- Digital Multimedia Appliances
- Ease of Use
- Home Networks
With client/server architecture taking over many traditional mainframe strongholds, formerly stand-alone PCs are being swept into distributed networks of desktop systems, typically with several server nodes that concentrate storage and processing. The need to interconnect is motivating widespread LAN installation and the high traffic levels are justifying upgrades to broadband premises equipment and wiring. This infrastructure is congenial to multimedia trials and experiments without depending on the applications themselves for justification. Workstations or PCs without network connections are becoming rarities. New workstations will incorporate affordable broadband (e.g., ATM) interface options on cards or motherboards.

Customer premise communication equipment (CPE) is likely to converge around ATM as a common technology that lets customers unify all their communications networks. ATM will blur the distinction between currently distinct traditional CPE equipment types (Switch, PBX, HUB, Router, Multiplexer, ...). Premises networks can offer broadband connectivity via FDDI, but at high costs for fiber installation and electro-optics. Broadband connectivity via ATM LANs has begun penetrating and should be dominant by the end of the decade. Interface cards and chips can retrofit in-situ twisted pair wiring to carry 100 to 140 Mb/sec to individual desktops, if it is high quality.

8.3.2. Multimedia Workstations

Reasonably priced multimedia- & video-capable PCs and workstations are beginning to appear (1995-6). As remarked earlier, they will have sharply increased computing power, storage, memory, display ability, and especially low cost video compression, electronics, and cameras. Again, the technology development does not depend on demand for business multimedia alone, but can be written off by broader markets (including stand-alone CD-ROM video, entertainment, pure vanilla videotelephony) that are large enough to create willingness to invest in aggressive development.

Desktops using multimedia-video are unlikely to demand more than 100 Mb/sec, even with uncompressed NTSC video (about 40 Mb/sec one way). With compression, video demands are likely to be well below 10 Mb/sec. Many current LANs can nominally support this, but contention between users would slow them to crawl with wide adoption of multimedia. The major applications needing burst speeds of 100+ Mbps might be client/server supercomputing (e.g., loosely coupled multiprocessing over LANs using RPCs between computing engines) or massive database transfer operations (e.g., super-fast image scanning).

8.3.3. Business Access

The LECs currently supply private line access bandwidth up to DS-3, still limited in availability and high in cost - affordable mostly to large facilities. Businesses - particularly those decentralizing - will adopt multimedia applications more readily when small business locations and residences (e.g., for telecommuters) also have reasonably wideband access (via T1’s) and can interwork with them.

Switched broadband services are needed to fully support multimedia workgroups, for example, unless the group members are limited to be in large facilities connected by private lines. Frame Relay and SMDS are unlikely to perform well for video - although some customers may use them - but should adequately support still imaging. ATM is designed for isochronous (real time) applications such as video and voice.

Competition between the LECs and third party access providers - Competitive Access Providers (CAPs) and CATV carriers - should speed up ATM deployment by all providers. The early ATM services are permanent virtual circuits (PVCs), with essentially the same limitations as private lines insofar as support for network-based M/V (Multimedia/Visual) services is concerned. B-ISDN (ATM switched virtual circuits, or SVCs) will mark the beginning of real access to M/V services in the network. By the end of the decade, B-ISDN is likely to be available for most large business users. Interim T1 access can improve coverage of large companies’ own branch offices. HDSL technology promises to improve the cost and speed of T1 provisioning.
8.4. Large Business - Multimedia Applications

Multimedia applications can be lumped into four classes: collaborative work, information access and retrieval, authoring, and visualization/simulation. The timeline in Figure 15 shows evolution from non-visual historical forms through an image/voice/data stage and then to video-capable and more integrated forms in 1996 and thereafter:

- **Multimedia Collaboration** - Interpersonal communication and cooperative work at a distance, using messaging and real-time technology. AT&T WorldWorx™ is a current version; releases to come will incorporate video communications. A number of individuals meet, via a bridge, while sharing some application (such as a spreadsheet) seen by and perhaps manipulable by all participants. The content may also include call center support for transactions or distance learning. Conference bridges may be hosted locally in on-premises servers or supported by network services. Similarly, multimedia databases may reside on-premise or be accessed through the public network (Multimedia 800/900) service.

- **Multimedia Authoring** - Creating and manipulating hypertexts in their multitude of forms, with intent to influence an audience. The publishing, training and entertainment programming content areas fit here.

- **Multimedia Information Access** - Organizing, reaching, browsing, retrieving, and changing information (including hypertexts). Image or video content residing in networked or local Information bases fit this template.

- **Multimedia Visualization** - Mimicking or imagining realities in order to visualize or predict behavior. These include simulations (local and distributed), computer aided design of all forms, geographic information systems, animation, etc. All forms share a tendency to be computation-intensive in the extreme with any data storage optimized for fast access at the expense of long-term storage efficiency.

Many - if not most - premise multimedia applications will descend from "legacy" business applications that become workflow and workgroup oriented. The bulk of most business's automated activities have traditionally centered on their production environments - typically tailored specifically to one particular company's detailed operations and typically residing on centralized mainframes. The simultaneous paradigm shifts to client/server plus multimedia are creating a unique opportunity to integrate voice/data/image/and video communication into these "mission-critical" commercial data processing systems: they can be modernized and given multimedia and cooperative work interfaces as they are rehosted. As applications ingest new the technology they will retain the business-specific differentiation developed for their owners at great expense over many years.

8.4.1. Multimedia Collaboration (WorldWorx™)

Multimedia collaboration / conferencing at the desktop or room will be useful in several grades of service, with or without motion video. Near-term multimedia collaboration services without video are attractive because they can be delivered using narrowband services such as ISDN basic service, or via a current packet service such as frame relay that won't support high quality video. The essential elements are good quality audio and the ability to exchange images and/or data in near-real-time.

A more powerful, but longer-term concept is that of the network-based virtual meeting service. Its deployment is still several years in the future, but prototypes are in hand. Some of the key features are:

- Flexible shared workspace capability with groupware support, including such appurtenances as blackboards and calendars.
- Interoperability - the ability to incorporate participants with more or less capable equipment (such as audio only) and equipment supplied by multiple vendors. Conversions between NTSC and PAL are a requirement for international traffic.
- Access to databases and library services
Workstation human factors will strongly affect the acceptance of desktop video collaboration. One key feature is full
duplex interruptible audio (for natural conversations). Eye contact two-way video (for creating the feeling of intimacy
and trust) and large screen size (to create convincing "telepresence") is desirable. Eye contact may be less critical
for cooperative work than for one-on-one conferencing.

8.4.2. Network-Based Multimedia Information Services

For information access, the cheap massive local storage (and computation) becoming available will compete
effectively with centralized information services delivered through a network when the databases are static. If the use
is frequent enough, users will choose to buy or lease a CD ROM or other reference and use it on their own
workstations at home or at work.

Network-based information services should have an edge when timeliness is the issue (monitoring markets, for
every example), or when the information is exotic and needed infrequently. Many attempts to market information services
have not met user acceptance in the past. Broadband networking and multimedia equipment with high resolution
image rendition may make a critical difference. The acceptance of local ROM-based information applications should
be a guide to the potential market for networked services.

Network information services may be reached by gateways to separate providers or by network-resident
databases that are built, maintained, accessed, and billed in support of a value-added offering. The technical
support needed involves massive, distributed databases containing imagery and video, meeting high demands for
access speed and transaction volumes.

8.5. Consumer Multimedia Enablers

The definitive new factors bringing multimedia to homes are affordable, intelligent, even brilliant, home appliances
(such as multimedia PCs, set-top boxes, game decks, and their descendants) and the consumer "information
superhighway" deployment that is likely to occur over the next few years. Access connections will support interactive,
broadband digital video and data services at home. Home-based multimedia applications will also be available at
reasonable prices, competing with and complementing network services, and making similar demands on home
appliances for user interfaces and processing support. Figure 18 shows a representative consumer services
architecture, incorporating competing access systems and client/server relationships between the network and home
appliances.

8.5.1. Growing Home Appliance Intelligence

The same IT forces that are at work in the business are also driving the consumer sector. Within homes, computing
intelligence can migrate to appliances (set-top boxes, PCs, game devices, etc.), and/or to centralized home
controllers that manage home networks (coaxial, twisted pair, wireless, etc.), provide uniform user interfaces, and
support non-entertainment home applications like security and environmental control.

It will become harder to define disjoint PC, telephone, and video appliance categories in the consumer domain past
the decade's end. It won't be very informative to describe an appliance as a "computer" when everything is one:
computers will become components, more than stand-alone products. The traditional expensive, monolithic PC
device won't suffice. Consumer markets' extreme price-sensitivity will invoke an analog of Gresham's Law: consumer
manufacturing technology seems likely to predominate and drive the high cost business platforms from consumer
applications.

Figure 17 shows four major areas in which consumer appliances will be transformed over the next decade. The vast
new design space created by the new technology and bandwidth (wireless and wired) will be filled by an initial
proliferation of offerings. Market forces will trigger a consolidation that kills off many products and features, beginning
roughly (and conjecturally) after about 1999.
Appliances are likely to remain split into narrowband versus video-capable/broadband species. Those designed to support personal mobility will feature wireless interconnects and become "brilliant" stand-alone, multi-use devices with many features. Stationary appliances can become modular components within centralized home systems, relying on their structure.

What will the “Home Information Appliance” be? Many in the industry believe that intelligent new set-top boxes will control home multimedia by virtue of their position on the TV set and access to CATV - the delivery vehicle for broadband digital video services. Others believe that the home multimedia PC coupled to on-line services will become the dominant appliance. It seems unlikely that a single device will become the "home information appliance": new kinds of intelligent appliances will still remain specialized to perform their main functions and be affordable. Most new appliances must remain differentiated to attract customers and be affordable; they add new functions using computer, video, wireless, and other technologies but do not necessarily fit the mold of historical appliances.

### 8.5.2. Consumer Multimedia Access Transformation

CATV and some local telephone companies are likely to deploy so-called "hybrid fiber/coax" systems in which optical fibers are run from the head-end or central office to local neighborhood nodes, replacing current coaxial feeders. Each node converts the signals and serves as a multiplexor/hub/switch for up to several hundred homes and small businesses. A coaxial distribution cable (perhaps the one there already) with bi-directional amplifiers runs between the neighborhood node and individual homes. There is no need to run fiber all the way to the home.
The usable bandwidth on the cable is increased (compared to current CATV systems) to the range of 1 Gigahertz as the number of analog amplification stages is reduced. In terms of digital data, it is practical to modulate at least 20 - 40 Megabits per second onto each NTSC standard 6 Megahertz frequency channel, using so-called "digital subscriber loop" coding/modulation schemes, exemplified by AT&T Paradyne's VideoSpan® Plus (a form of QAM, also known as "CAP" - carrierless amplitude and phase modulation). If the data represent compressed video (say, MPEG at VCR quality), then a 'fiber/coax' distribution system can have a capacity exceeding 500 channels.

The cable becomes a common bus local area network for a neighborhood - possibly divided throughout most of its bandwidth into 6 megahertz channels. Some of these remain analog and carry programming compatible with current cable converters. Many of the remaining channels each carry several compressed video programs. Others may be subdivided into narrowband circuits for voice or data, or simply be allocated on demand to subscribers as high speed data channels.

The systems will be two-way. Narrowband uplinks for voice and interactive TV, eventually with wider-band uplinks for videotelphony and high speed data will become available. The channel protocols will vary and may include ATM modulated onto traditional channel slots.

Other access media and variable standards will be used regionally. Some areas will be wired with fiber to or near the home - say with up to about 16 homes served by a local converter unit that supplies them with high speed twisted-pair and coaxial connections. Some may use digital subscriber loop technology on existing twisted copper pairs (ADSL, HDSL, VHDSL, ...) despite its generally limited bandwidth. Broadband wireless access using 28-30 gigahertz technology (LMDS) is a possibility in several years.
8.6. Consumer Multimedia Applications

The new applications and services will include content-based services and wireless and visual person-to-person communications. They will be received and consumed principally in people's homes - making newly affordable "cyberspace" applications that are something like the popularly hyped versions part of mainstream domestic lifestyles. The list includes "movies on demand" as the most oft-cited example, but multimedia education, gaming, voice and data messaging, and many others should flourish, given an infrastructure.

The new fusions of media and merged traditional applications are sometimes called "infotainment" or "edutainment", ... All of these terms convey information-intensive, visual, interactive, multimedia applications. They will also become new forms of expression that reorganize the traditional mind-sets regarding the appropriate forms of presentation, idioms, and user interaction, as the traditional businesses and their technologies fuse. For example, educational hypertexts will begin using techniques from imaging, video, and simulation gaming in order to promote learning more effectively and to hold the attention of a "heat seeker" generation that expects interactivity.

Video collaboration services probably have few initial customers in this market but will take root as forms of vicarious socialization when consumer videotelephony becomes affordable.

The problem of making this all usable is a significant challenge that falls on home systems.

8.7. Home Interactive Information Systems

New systems of appliances with expanded capabilities will be needed to deal with the added applications and new complexity. The architectures these home appliance systems need to have is insensitive to individual applications themselves but reflects more general platform and usability support they need (i.e., home and external networking, computing, signaling, appliance interoperability, etc.). Perhaps the most important need is easy to use, consistent user interfaces that make the systems usable by mere mortals.

These new "home interactive information systems" can be offered at affordable prices through technology advances. Appliances will be able to provide unprecedented versatility and capabilities but still be reasonably priced - computer-like, intelligent, even brilliant consumer products. "Moore's Law" and related arguments ensure this. The low cost, high performance technology supports a lot of new design freedom, allowing competing home system architectures to develop along with diversified appliances.

The major issue looming over home interactive systems is the following:

- Will home appliances become integrated systems - with appliances most tightly coupled to and inter-operating with others around the home through home network arrangements and controllers? This gives consumers the most freedom of choice in selecting suppliers of appliances, services, and electronic content and in personalizing the system. It especially helps consumers exploit the competition between multimedia (broadband) access providers that will evolve between CATV and local Telephone companies. Home controllers can select in real time from among the multiple providers. The systems migrate readily to an "electronic family friend" vision in the long-term.

- Alternatively, home appliance structures may remain extensions of the access provider's network into the home, strongly controlled centrally from a head-end or central office. This may minimize consumers' investment but it doesn't evolve readily (or robustly) to an "electronic family friend" since bandwidth and control are not at consumers' discretion.

8.7.1. Complexity and Interface Crises
The greatly increased access to entertainment, information, and visual communications will come at the price of dramatically higher complexity for potential users, as their equipment and options diversify. One set of problems is related to equipment incompatibilities. Another is related to the need for redundant equipment. A third involves complex and also varied and inconsistent user interfaces that baffle and confuse. The implied home interface crises arise because:

- new technology will be introduced with undefined usage conventions.
- converging computer, communications, and consumer appliance technologies carry traditionally different conventions and interoperability problems.
- similarly, applications and services from the converging industries will clash metaphors as they compete, consolidate, and change form.
- unfamiliar new applications and services will be introduced.

The impact will be to limit willingness to adopt more than a small fraction of applications available. A simplification must occur before mass acceptance can come.

Integrated home systems can address the need for improved interfaces and for availability of the new applications anywhere in the home. Two aspects of integrated home systems confront these issues directly:

- better and more consistent user interfaces, and...
- a true home video distribution network that provides "anywhere, anytime" access to video applications.

There is a niche market today for products that provide a subset of integration benefits. Many are found in consumer electronics retail catalogs, and a high end market exists coupled to videophiles and automation systems. Mass market possibilities for integration are foreshadowed by current, successful niche products such as universal remote controls, "rabbit" videocasters, etc.

### 8.7.2. Integrated Home Systems

The major challenge for consumer homes is to "glue" this melange together smoothly so that the result exceeds the mere sum of its parts. Integrated home systems may be the means for making that happen. Home information systems architectures should address the following four areas in order to meet the challenge and be survivable over the long-haul:

- **New Functionality** in home systems obviously requires new facilities that can host "cyberspace" applications in entertainment, work, and communication. These will use digital video, wireless, processing technology, be either networked or home-based, and offer multimedia content (video, information, games, ...).

- **Ease of Use**, a challenge because of the historically poor record for user interfaces in most of the computing and consumer areas: computers intimidate, consumer electronics baffle, keypads are easy but tedious to use, etc ... User interfaces need (at minimum) to become reasonably consistent, replacing the dissonant control sequences that make it so difficult to use more than a fraction of the functionality in today's appliances.

- **Personalized, Adaptive**, and simple programs and home-based user agents enhance ease of use (recall the 20%/80% rule). More ambitious agents support truly tailored, personalized, adaptive services. With time, the "electronic servant" applications can noticeably improve consumers' lifestyles.

- **Seamless Environment**. An integrated home system creates the illusion that it is a single entity whose components' abilities merge and complement each other without the user's constant awareness. In order to make
this happen, home appliances must inter-operate with each other smoothly, show at least quasi-consistent user interfaces at each location, and allow applications to run or be used on almost any suitable platform in the home. Integrated homes should also deal seamlessly with communication networks. Networked applications can become boundaryless, with users not needing to explicitly distinguish between local or networked interactions, or caring which vendor was chosen. Economic and preference choices would be made using intelligent controllers that perform access and service arbitrage automatically.

In the 2000+ era, home systems may evolve to a kind of "electronic servant". This vision is reachable technically, and also in terms of costs, customer lifestyles, and extrapolated demand. But its realization requires homes with integrated appliance architectures, and it is not guaranteed that short- and medium-term market forces will interplay in ways that bring these to pass. A major pivot point is the degree to which consumers can freely make use of and be isolated from multiple broadband access systems, competing for their business.

8.8. Mobile and Distributed Workers

A mobile and distributed market for multimedia combines elements of the other two markets, but stresses universally - or at least broadly available telecommunications services that can support it. It serves spatially distributed (or merely small) businesses and advanced general purpose communications. The initial communication services and style descend from telephony - audio conversations and conferencing.

Multimedia users can have "simple" videotelephones or more capable workstation equipment but are unlikely to have on-premises communications CPE or large servers. Distributed users will have to rely on public network-based video/image conference bridging and multimedia databases much more than will users in large business sites. Network-based switching and processing can effectively substitute for the large business premise facilities if adequate bandwidth connecting to network service complexes is available.

Carriers (LECs, IECs) will compete with each other and with gateway service bureaus (e.g., CompuServe) for this business. Near-term broadband access, where available, can be supplied by CATV-based "competitive access providers" and in some places via LECs. Wideband ISDN using HDSL or VHDSL may become common.

Business multimedia workstations and products for use at home will retain the computer industry flavor and emphasis on high end performance, along with high speed access (e.g., via ATM LANs), the need for desktop conferencing and collaborative work applications, fast database access and manipulation, high resolution graphic visualization, etc.

People wanting to use these to work-at-home will define a market for high speed data and videotelephony services, possibly ATM-based, that will make their connections almost as good as those in their offices, but delivered to sites on the local loop. High end users, however, will be a niche work-at-home segment; their applications should be able to ride on the consumer infrastructure but not determine its baseline to keep the mass market.


The preceding sections portrayed some capabilities of converging, powerful information technologies that will be available by the end of the century. Communication services' users will adopt new and better ways of doing business that the new capabilities imply, expanding their communications demands and expectations. Figure 19 juxtaposes the technology "push" forces described above with elements of the demand side "pull" as expressed by AT&T customers. The "roadmap" terminates on the sets of applications with greatest interest to large businesses.

The demand "pull" is created by informal processes in the IT industry that raise expectations before they can be satisfied. Large business customers are especially tuned in to emerging industry forces and are early signatories to
the vision. The early adopters of new technology may improve their ability to survive growing competition, at the expense of laggards. They will also face equals who have similarly “raised the bar” in technical sophistication.

9.1. Critical Customer Concerns and Impacts

Figures 20 and 21 respectively list many of the most critical business concerns expressed over the past three years by large AT&T customers, and the kinds of applications that impressed them as the ones with the most promise of improved competitive advantage.

Advanced networks are needed to satisfy these appetites. Some elements of the needed new infrastructure have begun to emerge:

- An advanced lightwave backbone that uses optical fiber speeds above 100 Gbps and advanced crossconnect technology.
- A broadband network incorporating advanced fast packet switch (ATM) technology, supporting new broadband digital services.
- Personal and wireless communication systems that interconnect seamlessly with public networks. These link local systems together and provide mobility management.
- Multimedia videoconferencing/collaboration services over public networks, including video, data, voice bridging and data structures that support virtual workgroups.
• Multimedia information services, some hosted on large platforms and located irrespective of traditional distance limits. They can be offered as value-added network services or third-party gateway offerings. In addition, AT&T can support independent information providers of many types by providing improved channels they need to reach customers, possibly via AT&T-provided front-end navigators.

• Flexible service control and billing is needed to manage the dramatically increased complexity and diversity of services.

**Figure 20: RECURRENT BUSINESS THEMES**

- **RE-ENGINEER PROCESSES FOR COMPETITIVENESS** (response to market, customers)
- **DIFFERENTIATE FROM COMPETITORS** (user interface, service, customization, …)
- **REACH AND SATISFY END-USERS** (segmentation, targeting, …)
- **OPERATE MORE EFFICIENTLY** (costs, productivity, inventory, workflow, …)
- **EDUCATE & TRAIN BETTER** (workforce limits, obsolescence, …)
- **CONFIGURE WORKFORCE FLEXIBLY** (decentralization, mobility, …)
- **FOCUS ON CORE COMPETENCIES** (outsourcing, end-to-end solutions)
- **INTEGRATE CUSTOMER & SUPPLIER SYSTEMS** (electronic bonding, collaboration)
- **PARTNER, EVEN WITH POTENTIAL COMPETITORS**
- **USE INFORMATION MORE EFFECTIVELY** (critical to success)

**CUSTOMER RESEARCH-DRIVEN**

9.2. Summary - Vision and Implications for Technology Capabilities

Figure 22 shows the six “themes” in BMS’s long-term business vision. They represent large families of potential services that address the future of this industry frontally. Customers will develop an expectation of increasingly sophisticated communication and information services while enjoying intuitive and effortless interfaces to them. Many offerers, as well as end-users, of communication and information services wish to be shielded from the complexities of providing them. The enabling technologies discussed above map onto the “themes” as follows:

- **Multimedia Visual Services** leverage technology related to multimedia and broadband transmission, advances in compression, processor power, multimedia databases, user interfaces, and displays.

- **Image Movement and Management Services** similarly leverage fast, efficient, broadband transmission, image compression, storage technology developments, image processing and recognition tools to make the manipulation of images in networks dependable, value-added, and inexpensive.

- **Advanced Voice Services** Technologies related to the voice recognition are the key determinants in this area. These include both coding algorithms and processor technologies. Traditional digital signal processing and high speed parallel processing both have impact in the realization of Advanced Voice Services. Progress in software
techniques and mathematical modeling also are necessary for this theme to be developed to full commercial opportunity.

- **Mobility Services:** In this theme, the leading technology is clearly wireless. However, as this theme is defined, it embraces the delivery of network services to a person, not a location. Therefore, features accessible on a wired network connection are part of this theme. For example, professionals wishing to interface to the network (both place and receive communications) in the same manner regardless of their location would be presented services under this theme.

- **Advanced Information Services:** Important technologies include object oriented programming, intelligent user agents, directory services, information indexing, knowledge based expert systems, neural networks, parallel processing, digital signal processing and pattern recognition systems. This theme addresses the evolution of Information Services to Knowledge Services through the use of technological advancements. Inclusive to this theme are services which would be available in multimedia form or to a mobile customer.

- **Multimedia Broadband Networking:** This theme addresses the significant challenges in providing network bandwidth and (more importantly) capabilities to meet the demand of the many anticipated multimedia applications that will be desired by users.

**Figure 21:** APPLICATIONS/TECHNOLOGY WITH HIGH CUSTOMER INTEREST

- **CLIENT-SERVER, DISTRIBUTED DATABASE NETWORKING (a given)**
- **GROUPWARE/COLLABORATION, WORKFLOW AUTOMATION**
- **VIRTUAL OFFICE, REMOTE WORKER, NEW DISTRIBUTED ENDPOINTS**
- **MULTIMEDIA VISUAL/IMAGING APPLICATIONS AND NETWORKING (Growing interest re core processes, but with cost concerns)**
- **EASE OF USE, COMPLEXITY CONTAINMENT ON EVERYONE'S WISH LIST**
- **FOCUS ON SOLUTIONS AND VERTICAL INDUSTRIES (Interoperability, end-to-end, integration of services, hardware, applications)**
- **INFORMATION ACCESS AND UTILIZATION**
- **PERSONAL SERVICES BASED ON PROFILES AND AGENTS**
- **GLOBAL COMMUNICATIONS (competitive differentiator for TelCo's)**
- **SECURITY, ESPECIALLY FOR MISSION-CRITICAL APPLICATIONS**
- **PRICE STILL A CENTRAL ISSUE**

**CUSTOMER RESEARCH-DRIVEN**

9.3. **Conclusions**

Many technical advances need to be adopted and deployed in order to realize the AT&T BMS vision of the future. But communication services alone, or equipment alone, do not always solve business problems for customers. That takes an end-to-end approach.
AT&T needs to partner with its business customers, as they desire, providing IT expertise, communications services, end-to-end and integrated solutions that help them achieve competitive advantage, in traditional and non-traditional markets. The range of scales covers desktops through global networks.

Figure 23 summarizes some of the many areas of joint activity that may be explored. Integrated Solutions adds value to piecemeal and in-house approaches by viewing and solving IT problems from a long-term business perspective.
Figure 23: INTEGRATED SOLUTIONS ARCHITECTURE

END-TO-END DESIGN
SYSTEM INTEGRATION
ONGOING SUPPORT

PROFESSIONAL SERVICES

PREMISES
APPLICATIONS
- enterprise-specific software
- legacy migration support
- integrated voice/data, multimedia, messaging, ...

COMMUNICATIONS SYSTEMS
- PBXs, switches, hubs, routers, BOSs
- LAN & premise wiring, wireless media

INFORMATION SYSTEMS
- OS systems, software & middleware
- desktop workstations, communication, terminals, wired & wireless, ...

REMOTE WORKER
APPLICATIONS
- enterprise-specific software
- migration support
- integrate voice/data, multimedia, messaging, ...

ACCESS SERVICES
- TP, wireless, cable
- shared local access points and connections to enterprise networks
- narrowband to broadband

END-USER DEVICES
- home, mobile, small office, ...

WIDE AREA & GLOBAL
NETWORKED APPLICATIONS
- enterprise-wide and vertical packages
- multimedia visual, image, advanced voice/data
- information, mobility
- service platforms
- multimedia migration support

SWITCHED AND POINT-TO-POINT COMMUNICATIONS
- enterprise networks
- narrowband to broadband

DEDICATED ACCESS FACILITIES