

# Research Challenges in Wireless Multimedia

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**Abstract:** The near future will bring the fusion of four rapidly evolving technologies: high speed networking and associated services, wireless communications, scaled integrated circuit technology, and multimedia-based applications. These new technologies will enable the access of multimedia data from network servers at any time and any place by light weight, low cost wireless terminals.

the Internet becomes increasingly available and desired by the general public and the dependency on access to these information sources grows.

Major research activity will be required to develop the technologies to support ubiquitous access to these evolving network services through a wireless, multimedia terminal, as shown in Figure 1. To define the capabilities that must be supported by a wireless information access system, the characteristics of present services will now be analyzed and predictions made of possible future services.

## I. INTRODUCTION

The expansion of Internet activity which is now taking place is an important indicator of the future environment which will require wireless multimedia. From February to March, 1994 the data traffic over the NSF backbone in the U.S. increased by over 20%, from 9 terabytes to over 11, providing new network services of all types to over 20 million users. It is expected that an exponential growth will continue as awareness and access to

### *Text/graphics databases*

Servers presently provide access to text and graphics commercial databases containing a wide spectrum of information, including international and domestic news, weather, financial information, stock pricing, traffic data, transportation schedules, electronic and voice mail. This will expand in the future to provide educational informa-

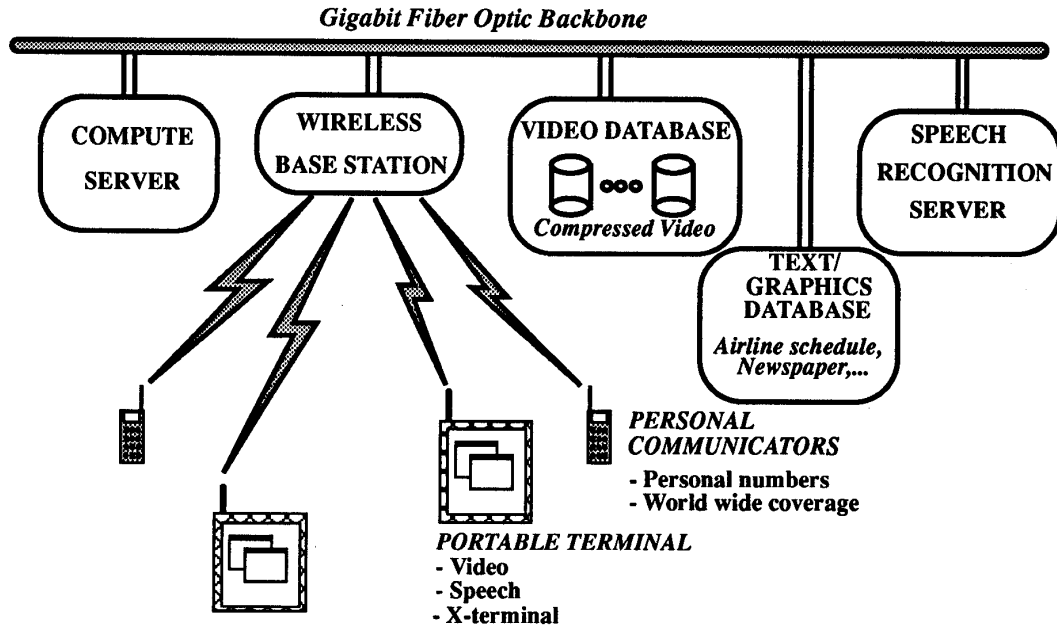


Figure 1. Future infrastructure for information access

tion which includes on-line textbooks and libraries, health care information and databases that support electronic commerce. A key characteristic of this data is that the value of the information is time critical because of its transitory nature, which renders distribution by off-line means such as CD-ROM impractical. In addition, information which is static -- a digital library, for example -- is often very large, again requiring on-line access to the data servers.

#### *Video databases*

Future applications will utilize video databases containing both entertainment and educational media: animated information sequences, taped lectures, movies, news clips, and other forms of video and audio data will impact the ways we learn, work and entertain. Unlike today's television broadcasts, such video would be available in a per-user, on-demand basis. Video will necessarily be stored in a compressed format, for minimization of both storage space and transmission bandwidth, thus requiring that access terminals support video decompression.

#### *Compute Servers*

Though it is expected that the primary focus of the network services will be information access, entry and manipulation, there will be also be need for computational support. The placement of this computation is expected to move from the portable unit, where power consumption and cost are an issue, to the backbone network where the computation can be performed in either distributed or centralized compute servers.

Client-server computing environments, such as those based on the X-window system have demonstrated that computation need not necessarily be done on a local machine (the display server) that a user is operating; but can be done by programs executing on many remote machines (clients), that simply issue graphics commands to the server to display their results. Many inexpensive "X-terminals" already exist, without any user accessible computation capability. The design issue of where the remaining computation is performed to execute the graphics commands is dependent on the ability of the network and wireless communication link to support data transfer with sufficiently high bandwidth and integrity at low enough latency.

#### *Advanced User Interfaces*

The design of an effective user interface to access the future services is a critical issue, since the primary user is the general public who will require significantly simpler access mechanisms. When supported by speech and handwriting recognition, audio and pen-based input offer considerable improvements over the keyboard and mouse mechanisms for multimedia applications. The placement

of the recognition servers again need not necessarily be in the portable, but as in the case of the compute servers, these services can reside on the network, enabling the use of the most sophisticated recognition algorithms. Optimizing these recognizer servers to a given application, by determining which words are most likely to be used, can yield further improvements in recognition accuracy.

#### *Electronic commerce*

The ability to advertise, provide product information, buy and sell over the Internet will become one of the most important application areas, because through these activities the financing can be justified to extend the infrastructure to an ever wider number of users. Advertising and product information over the network will make use of the multi-media capabilities of the network (text/graphics, audio and video), but with very asymmetric communications - since the user (customer) will primarily only need to control the information flow and indicate transaction decisions. Security/authentication is clearly a prerequisite before this application can become widespread and will have to be an integral aspect of the system design.

## II. USER SCENARIOS

The general public at home who are becoming aware of the advantages of accessing information over high bandwidth networks, will ultimately be the majority of users. They will access information for entertainment, educational, financial purposes as well as communicate with others and their workplace environment. Ease of use requirements are also coupled with the necessity that the cost must be extremely low, including all infrastructure, since the user density at each home is relatively low. It is felt that the investment per user should be less than \$500 (US) and the monthly cost should be at the level of present cable and telephone services (\$20-50).

K-12 Education also needs a system that is inexpensive and cannot require highly technical personnel to operate. In addition, the density of users is high, but in a closed environment in which the cost of the infrastructure can be shared. On-line textbooks, digital libraries, educational video databases and the ability for students to not only access information, but enter information for other students to use, is a vision of the future that is being promoted by education researchers.

Health care will also be impacted in a number of ways by the future networked environment. In hospitals, the density of users is moderate, and again in a relatively closed environment in which a relatively sophisticated infrastructure could be provided. The users are workers who are relatively mobile (within their closed environment) and need access to a wide variety of information - e.g. patient records, medical journals, books, and medic-

inal information. They are highly motivated to be as efficient as possible in their activities, and are very receptive to a system that would provide them ubiquitous personal information access.

### III. SYSTEM SPECIFICATION

Some of the critical technical requirements of a system that is designed to support the above scenarios will now be described [She92]. The most difficult requirement is to keep the cost of the overall system sufficiently low for the mass-market applications on which we are focused. This is best addressed by using standard CMOS technology in the implementation, ultimately including even the radio circuitry, and by investigating cost issues of all aspects of the design, including the packaging and I/O devices.

#### *Multimedia access*

The future high bandwidth communication networks will still deliver voice to end users, but that will only be one of the many services provided. Users will also require video, text/graphics, and audio to fully support future applications which distribute information. The phenomenal growth of the World Wide Web and associated Mosaic client for viewing the multimedia information on the Web indicates the demand for such information.

It is believed that a substantial fraction of Internet traffic is in support of Web access, which is particularly amazing in the light of the relatively low transmission speeds of much of the Internet (typically 1.5 Mbit/sec or less with actual end-to-end rates 10 times lower). To support interactive access and to simplify user interfaces, support for handwriting input and voice-controlled applications will be required.

#### *Terminal Portability*

Convenient, ubiquitous access to the network dictates that the I/O device be portable. The resistance to reading large amounts of text on a computer screen, instead of paper, is due in large part to the inconvenience of the usual fixed desktop placement of the screen. However, when multimedia data formats are incorporated into a document the use of paper becomes obsolete, in spite of its historical significance and continuing proponents. Thus the electronic viewing device should have the convenience of paper, yet retain the capabilities of an advanced multimedia desktop unit. This implies the portable device should weigh less than a pound and a form factor that allows convenient observation (such as a full size 8x11 inch notepad) with a long battery life (week or more), while providing color video and audio output and pen and microphone inputs.

There continues to be rapid progress in the area of LCD displays which usually require a backlight to give sufficient contrast that dominates the power consumption of most portable terminals. Fortunately, there has been recent disclosure from Sharp of reflective color displays which consume only 50 mW for a 5" panel. Though this is still too small at this time, it is clear that the continuing development efforts in LCD technology will provide an adequately low power display solution.

#### *Wireless Communications*

The most demanding requirement of the notepad is the requirement that full motion video be transmitted over a wireless downlink from a base station, which performs the interface between a high bandwidth network backbone and a portable notepad. Video quality equivalent to present day television can be compressed to rates on the order of 1-2 Mbps, which sets the minimum data rate for this link. The data on the uplink (from the portable to the base station) is audio and pen data, which can be adequately transferred by a rate of 64 kbit/sec.

Thus the link is quite asymmetrical with a downlink requirement of more than 10 times the uplink rate, a factor which can be taken advantage of in designing the uplink radio system for the portable pad. Video for teleconferencing may be desirable on the uplink, but compression algorithms for this application are in use that only require data bandwidths of a small multiple of 64kbit/sec, thus retaining the asymmetric nature of the wireless link.

In order to provide high bandwidth (1-2 Mbps) wireless communications to a high density of users, in a reasonable amount of spectrum, extremely efficient use of the wireless media must be employed. Infrared is appealing because of the isolation which can be achieved between rooms, however the composite data rate to support a high user density such as found in a classroom (50 users at 2 Mbps) has yet to be demonstrated.

A radio solution must also utilize high levels of reuse, but the inter-cell isolation is not as effective since radio is able to penetrate non-metal barriers. Therefore the high levels of reuse result in an interference-limited channel in which the primary contributor to bit errors is transmission from other users and other base-stations. This is optimized by reducing the size of the cells to the smallest practical size (5-10 meters), with an associated reduction in the transmit power levels to well under 1mW.

The wireless link design then becomes a trade-off between capacity and interference, which can yield at maximum user density, bit error rates as low as  $10^{-2}$  -  $10^{-3}$ . This places a significant limitation on the kind of data that can be transmitted over the wireless link since this

data must be robust against corruption. An ARQ or retransmit protocol (e.g. TCP) could be used to insure end-to-end data integrity, but at the high bit error rates of this wireless link, the loss in throughput and increased latency is unacceptable for the required real time I/O data (audio, text/graphics and video).

It is interesting to note that as the amount of compression for the I/O data is increased, it is often necessary to increase the level of error protection, because of the increased sensitivity to errors of the more compressed data. Compression algorithms that are optimized for both the amount of compression, as well as the robustness against errors, result in a data stream which requires less error protection, which in turn yields higher quality at lower transmitted bandwidths.

#### *Backbone Network*

The bandwidth of the backbone network is assumed to be sufficiently high that the multimedia data can be supplied to the many users, who could potentially be in a relatively small area, e.g., in a classroom situation. This, however, is not expected to be a major problem, since the wireless link will place a severe restriction on the data rates that can be delivered to the user (approximately 1-2 Mbps in our design). Thus, in a classroom of 50 users which are all served by a single base station at the maximum data rate, the composite rate would be less than 100mbit/sec -- a data transfer rate well under the capabilities of even present day networking technology.

The protocols needed in the wired network must be enhanced to encompass the unique requirements of the multimedia portable terminal. In particular, the network must be able to provide routing to a mobile host, while retaining the present inter-networking capability of TCP/IP. Since the cells are small, there will be many transfers (handoffs) between basestations, which requires the adaptive routing to these moving users to be very efficient [Kee90]. The data which is being transferred to the users has real-time requirements, and thus some form of bandwidth and jitter guarantees must be provided by the backbone network. This must be accomplished through a quality of service negotiation, between what the time-varying wireless channel can support and the network servers can provide.

A more difficult requirement is the round trip latency between the portable terminal and the servers on the fixed network. This includes all the processing required in the portable unit and associated base-station, along with the network latencies associated with the gateway between the wireless and fixed networks and the delays in the internet itself. Latency control is most critical in those applications in which there is a tight interactive loop between the user input and the display output. The latency which can be tolerated is actually quite similar

for the various kinds of I/O data. If the delay between the drawing of electronic "ink" on the pad and the subsequent re-display on the text/graphics screen is performed under 30 milliseconds, it will not be detected since this is the update rate of the display. Similarly, experience with echos in long distance phone connections shows that delays under 30 milliseconds are also not objectionable to the user. Thus a latency specification of less than 30 milliseconds appears to be adequate.

#### IV. INFOPAD PROJECT

A research project is underway, called InfoPad which takes one set of solutions to the above requirements. Specifically, a light-weight portable pad designed provide access to a variety of network services over a high speed backbone, and which will run protocols to support mobility and real-time data, is being developed.

The design of a complex system such as the Infopad requires a careful trade-off between cost, size, functionality, flexibility, communication bandwidth and reliability. Making these trade-offs requires a design methodology that supersedes the component level and addresses architecture, algorithm and protocol selection as well. Also essential is to include power consumption as an intrinsic element of the design cost, as the portability requirement makes power minimization one of the prime design requirements.

The design of the first prototype pad has been completed which supports both pen and audio input, with text/graphics and audio output, and is thus termed the IPGraphics pad. A chipset that supports video decompression and display was designed, fabricated, and successfully tested, will also be described. Although they do not support the capabilities we ultimately require of the wireless link, commercial radios were used in this first design; they allowed investigation of issues relating to data throughput, channel models, and the effect of bit errors on the applications and wireless protocols. An integrated CDMA radio that is being designed to meet all the Infopad requirements [She94] is also being developed. Network software for this first prototype was written for only a single user with a single base station to facilitate measurements of the latency obtained when data is transferred from the portable pad, through a base station to the wired network and back again.)

#### V. LOW POWER MULTIMEDIA TERMINAL CHIPSET

One of the early returns was the importance of reducing power consumption and the need to take a system viewpoint to its minimization. The primary challenge of reducing the weight of the terminal is the power consumption of the circuitry to convert the data from a raw 2 Mbps downlink data stream to the form required by the

video and graphics displays and audio output [Cha94]. The most demanding function is the decompression and associated frame buffering of the video data which must be performed in real time and its subsequent conversion to analog signals to drive the LCD display.

One important strategy for accomplishing this is to move as much of the processing as possible out of the portable unit into servers on the network. This results in a design in which there is no user accessible computation in the portable pad, which not only relieves the portable unit of the requirement to support a general purpose operating systems (e.g. Windows NT, Unix, etc.), but also eliminates the need for expensive and power hungry mass storage devices, costly memory and, implicitly, a high speed general purpose processor sub-system.

By optimization of the circuit design for the chips which support all the pad operations, it was found possible to reduce the power consumption to 5 mW. A key component of this reduction was the use of low supply voltages, which could be as low as 1.1V. This has other system implications, namely the need for efficient DC to DC conversion, which provides yet another new research focus.

#### VI. CONCLUSION

A number of new research challenges must be faced before the goal of providing ubiquitous access to information from high bandwidth networks can be realized. Research is needed at all levels, extending from the circuit design in the portable units, through to the protocols on the high speed backbone networks. In addition to enabling ubiquitous information access, research in these areas will provide many fallout contributions to a wide variety of other important future applications.

#### *Acknowledgments*

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