# Deploying ATM Residential Broadband Networks

Mark Laubach, Chief Architect
Com21, Inc., 1991 Landings Drive, Mtn View, CA 94043
laubach@com21.com http://www.com21.com/

*ABSTRACT*

*ATM residential broadband technology is rapidly entering commonplace discussion. The capabilities provided by ATM network interface devices promise data bandwidth speeds far in excess of those provided by traditional twisted pair public telephone networks. Cable TV operators and Regional Bell Operating Companies (RBOCs), e.g. PacBell, are preparing for this integrated broadband future by installing or rebuilding existing all-coaxial cable plants into two-way Hybrid-Fiber Coaxial plants and by offering a wide range of both data and interactive services which they feel will be most attractive to their subscriber base. Initially these services will only provide Internet access and access to the major information service (e.g., Compuserve, AOL, and Prodigy). These service offerings will quickly advance to support multiplayer gaming and collaborative services such as voice and desktop video teleconferencing.*

*As an introduction to some of the issues surrounding ATM residential access technology, this paper summarizes two of the standardization efforts: the ATM over HFC definition work taking place in the ATM Forum's Residential Broadband Working Group and the standards progress in the IEEE P802.14 Cable TV Media Access Control and Physical Protocol Working Group. Delivering ATM-based integrated services via a Cable TV has its own set of deployment issues and benefits that are briefly overviewed and summarized.*

## INTRODUCTION

Packet technology has been around since 1964 [8]. Since then, the size of packets has been debated, as well as variable vs. fixed size. Packets are transmitted over any media these days however, the next economic and technical frontier is moving packets over Cable TV (CATV) networks. The driving push is to deliver IP datagrams over cable TV networks. There are several datalink methodologies for delivering IP datagrams via cable modems, This paper overviews the notion of sending small, fixed sized packets over the CATV plant. These small packets are 53-octet Asynchronous Transfer Mode (ATM) cells [1]. In addition to meeting this *Internet rush*, ATM provides an integrated services base on which to offer additional services.

The term *cable modem* has been associated mostly with a description of a CATV Internet access device located in the home. ATM based systems allow the deployment of other services beyond basic Internet access. In this latter use, the ATM-based cable modem can be viewed as a broadband services interface for the home, or an ATM Network Interface Device (NID) or an ATM Premises Interface Device (PID). These terms are synonymous in their use in this paper.

Numerous standards organizations are gearing towards producing cable modem standards. The ultimate goal of each is to drive cable modem availability to commodity status and made available via consumer *off the shelf* purchases at computer boutiques and electronic supermarkets. The minor problem with the commodity process is that these numerous standardization activities are competing and largely uncoordinated and there are about a dozen cable modem manufacturers producing product, some of whom wish to establish defacto standard status by being first to market.

The IEEE P802.14 Cable TV MAC and PHY Protocol Working Group is chartered with providing a single MAC and multiple PHY standard for cable TV networks. The efforts of P802.14 must support IEEE 802 layer services (including Ethernet) and must also be *ATM Compatible.* ATM residential broadband work is currently taking place in the ATM Forum.

The customer network interface *du jour* is Ethernet 10BaseT. There is a mandate for a 10Mbps Ethernet interface in the home. Subscriber access equipment can be a personal computer, X-Terminal, or any such device which support the TCP/IP protocol suite.

## Engineering Challenges of ATM over Cable

The standardization and implementation of two-way interactive services on Hybrid Fiber-Cable (HFC) TV networks is fraught with many engineering problems which must be overcome:

- CATV systems are inherently asymmetric in nature, i.e. there is more downstream bandwidth available than upstream and interactive services such as voice or video telephony require symmetric data rates. ATM based services will create an environment where symmetric virtual circuits will be opened and closed frequently.

- High utilization of the upstream bandwidth is necessary to be cost effective and accomplished by sharing bandwidth between stations with the access based on dynamic assignments within a slotted regimentation.

The choice of the allocation protocol and the placement of the bandwidth ownership intelligence is important. A straightforward approach is to place the ownership of the upstream bandwidth under the direction of the head-end controller which is tightly coupled with the ATM traffic and signaling management processes. This also has the effect of reducing complexity in the subscriber unit and by centralizing the allocation intelligence in the network. Communications between the head-end controller and each subscriber unit is important as permission to use the upstream channel is granted by the head-end controller whose allocation algorithm must take into account the needs communicated to it by each subscriber.

## ATM in the Residential Broadband Network

The selection of ATM cells as the data-link layer protocol data unit for Cable TV networks has the advantage in that it provides a suitable integrated multiplexing platform capable of supporting a mix of guaranteed (predictive) traffic flows with best-effort (reactive) traffic flows. In addition, the nature of ATM allows other multimedia applications to be added in the future without requiring iterative changes to the basic ATM protocol. Cable operators can deploy ATM systems as part of an evolutionary path to a fully integrated multimedia bearer service offering.

An ATM data-link protocol can be layered in a straightforward manner for both the downstream and upstream segments of a cable modem network, The challenges are that upstream traffic management and resource management must be creatively controlled to support the guaranteed and best effort Quality of Service (QOS) needs of the cable modem. A residential ATM bearer service easily supports Internet access to the home via the Classical IP over ATM standards of the Internet Engineering Task Force [3] or by providing an IP over Ethernet adaptation overlay service.

While ATM in the home is desired as a future interconnection method by some HFC operators, the cost burden of the ATM interface is not economically feasible today. It is expected that ATM network interface controllers will be decreasing in cost quickly over time so planning a cable modem bear service now to

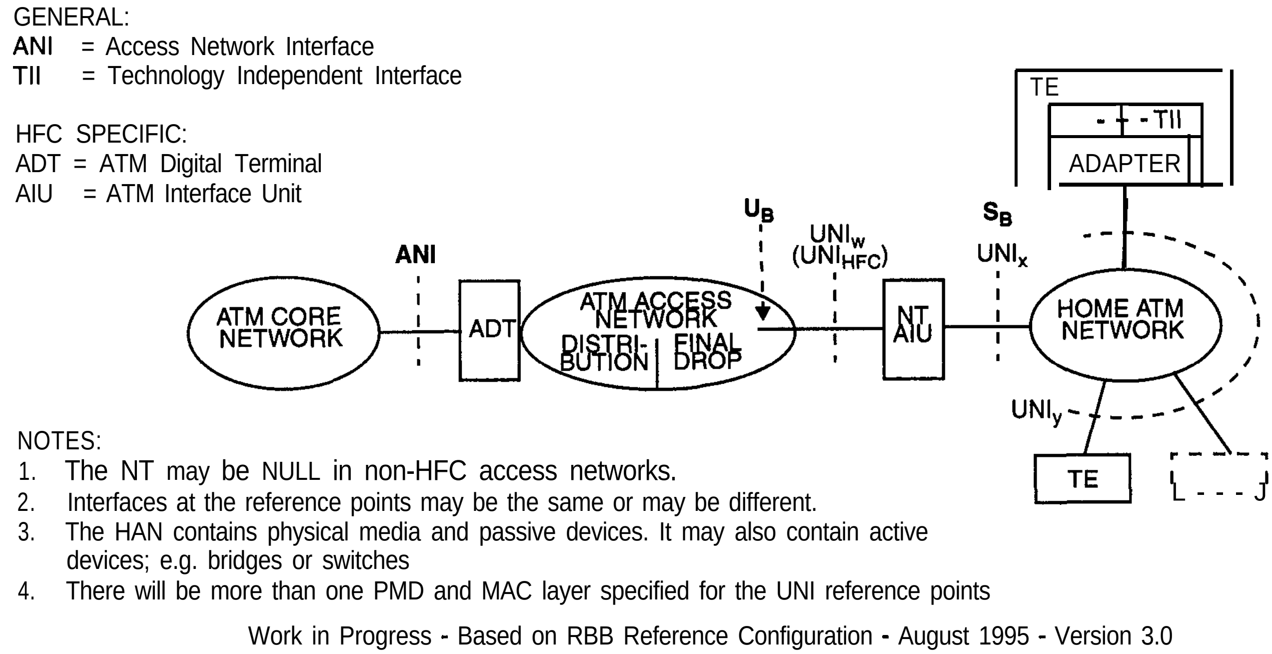


**Figure 1. ATM Forum Residential Broadband Reference Model**

support both Ethernet and ATM home interfaces can be viewed by some as prudent.

## ATM FORUM'S RESIDENTIAL BROADBAND WORKING GROUP

The ATM Forum is focusing attention on delivering ATM over residential broadband distribution systems. This work is being carried out in the Residential Broadband (RBB) Working Group (WC). The material presented in this section represents work in progress in the ATM Forum and is offered as an example of the current thinking on the subject. At some time in the future, the ATM Forum will be producing a published specification which includes the ATM over HFC UNI details. The ATM Forum is a closed industrial consortium requiring membership dues for participation.

The two goals of the RBB WG are to 1) deliver ATM to the home and 2) deliver ATM within the home. These can be euphemistically termed as *the last mile* problem and *the last yard* problem. The current proponents of ATM over HFC systems are concerned with delivering a full function UNI interface to the home via an active Network Interface Unit (NIU) termed an ATM Interface Unit (AIU). Controlling the system is a ATM Digital Terminal (ADT) located at the cable system head-end (see Figure 1) The discussion of ATM within the home is beyond the scope of this paper.

The ATM Network Interface (ANI) defines the connection between the ADT and the ATM WAN network. This interface may either be specified as a Network-Network Interface (NNI) or as a UNI. The AN1 will be based on existing ATM standards and the WG expects complete compliance with existing physical (PHY) interface standards.

The HFC access network is in effect a *black box* to the ATM Forum's design activities. It was decided early in the RBB charter process, that the RBB WG will rely on the efforts from IEEE P802.14 Cable TV MAC and PHY Working Group for the transport of ATM cells over the HFC network. The UNI-HFC will define an RF interface for the ADT and AIU. A possible protocol stack representation of the relationship

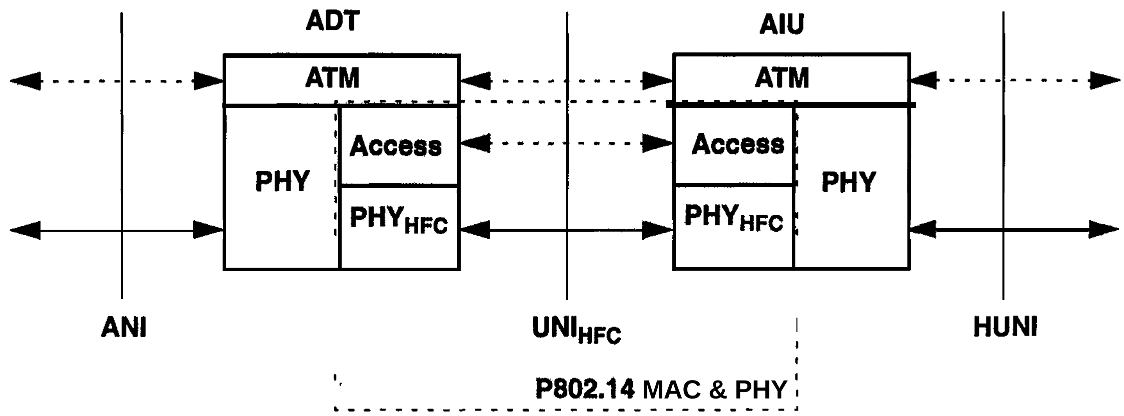


**Figure 2. Proposed ATM Transport Protocol Model**

between ATM and P802.14 is shown in Figure 2. It has been suggested that communication between the ATM layer and the IEEE access layer be specified via an abstract layer interface definition, which will be referred to as the access interface in this paper.

The AIU provides an ATM UNI to the home. This Home UNI (HUNI) interface is meant to be as standard as possible. It will most likely provide a subset of UNI 3.1 or the upcoming UNI 4.0. It is expected that this interface will deliver the full range of CBR, VBR, ABR, and UBR services. However, the real performance of these will be limited by the available performance offered by the HFC access network and the characteristics of the underlying P802.14 MAC and PHY.

The RBB WG effort is current work in progress. It will produce an implementation reference (i.e., a $UNI_{HFC}$ implementation reference) which is synchronized with the IEEE P802.14 working group. At the time of this writing, the following issues will need to be resolved within the RBB:

- How Virtual Path Identifiers (VPIs) and Virtual Circuit Identifiers (VCIs) will be used within the UNI-HFC and how they are mapped to the IEEE access interface.
- Where and how does ATM UNI Traffic Management (TM) take place in the HFC system, and the nature of the QOS or TM interface to the IEEE access interface.
- What form of UNI signaling will be supported between the ADT and the AIU. The AIU might be passive requiring the ADT to perform proxy signaling on behalf of the home UNI. If all AIU interfaces share a common VCI space, then meta-signaling may be required, etc.
- Will the ATM over HFC system specification include telephony voice over ATM and if so, with what Cell Delay Variation (CDV)?
- What are the required performance goals for ATM peer-to-peer networking when operating over an HFC network.?

The above issues and more will be addressed in the ATM Forum's efforts.

## IEEE P802.14 CABLE TV MAC AND PHY PROTOCOL WORKING GROUP

In November, 1994 the IEEE P802.14 CATV MAC and PHY Protocol Working Group met for the first time as an approved project within the 802 standards committee. Previous work had been done in the 802.catv study group in preparation for formal approval. The Project Authorization Request (PAR) charter of the group specifies that it will standardize a single MAC layer protocol and multiple PHY layer protocols for two-way HFC networks. Consistent with the IEEE LAN/MAN 802 Reference Model [5], P802.14 will produce a solution which supports the 802 protocol stack while at the same time supporting ATM in an *ATM Compatible* manner.

The WG has completed a first release revision of a functional requirements document [4] which details the P802.14 cable topology model; defines key assumptions, constraints, and parameters; defines key performance metrics and criteria for the selection of multiple PHY protocols and a MAC protocol; and defines the support of QOS parameters. The working group's work plan called for the close of formal proposals in November 1995, with the recommended protocol defined in July 1996. Seventeen MAC protocol proposals were submitted to the working group. It is anticipated that the WG will select the best features from amongst the proposals and apply appropriate glue to form the standard. The IEEE is a public standards organization and anyone may participate in the standards activities.

The branch and tree topology of a Cable TV single-cable distribution network is divided by RF frequency into a downstream portion (typically 50 Mhz to 550 Mhz or 750 Mhz) and an upstream portion (typically 5 Mhz to 40 Mhz). Both downstream and upstream frequencies are active on the same physical coaxial RF cable, and the use of bandpass filters and diplexors provide the spectral separation necessary for the simultaneous amplification of signals in each direction. A P802.14 subnetwork can be thought of as a single head-end controller communicating with a set of cable modems. via a MAC protocol operating of a collection of downstream and upstream PHY channels (see Figure 3) Home Network Interface Units (NIUs) will communicate with the head-end terminal unit using the agreed upon downstream and upstream PHY. The downstream PHY will support a broadcast, one transmitter many receiver model. The upstream PHY will support a one receiver many transmitter model, requiring that the upstream PHY be shared amongst all participating NIUs in the subnetwork.

The general P802.14 requirements are: support of symmetrical and asymmetrical rates on connections involving the downstream and upstream channels; support of Operation, Administrations, and Maintenance (OAM) functions; support of one way delays on the

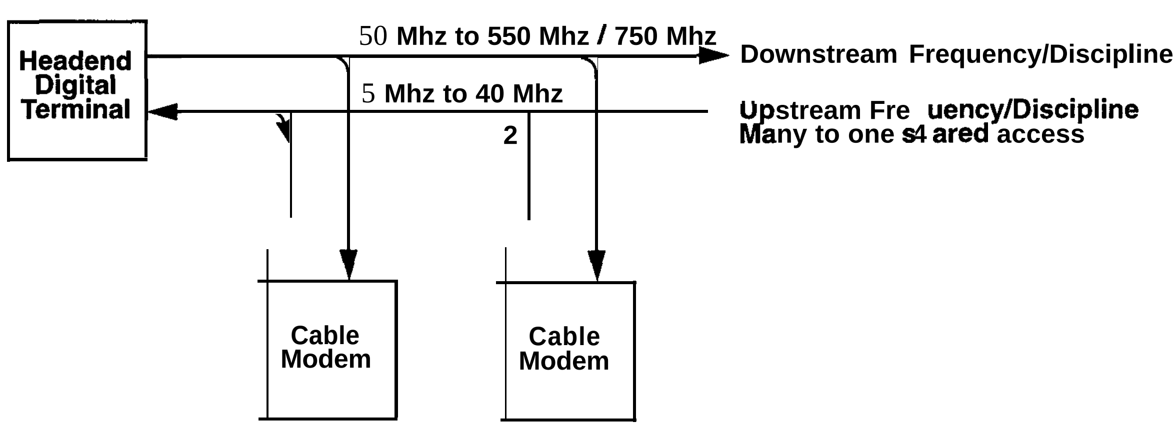


**Figure 3. IEEE P802.14 Shared HFC Architecture**

order of 400 microseconds (round trip delays to 800 microseconds) support of a large number of users; support for moving data from an originating sub-network to a destination subnetwork which may be the same or a different one; and the option of a customer reference point between in-home and external networks.

The P802.14 MAC layer requirements are: support of both connectionless and connection-oriented services; support of a formal QOS for connections; support for dynamically allocated bandwidth for different types of traffic, including Constant Bit Rate (CBR), Variable Bit Rate (VBR), and Available Bit Rate (ABR); support for unicast, multicast, and broadcast services; interoperability with ATM; predictable low average access delay without sacrificing network throughput; and fair arbitration for shared access to the network within any level of service.

The P802.14 PHY layer requirements are: HFC system size up to 500 households as a reference design point; primary support of sub-split cable plants (5Mhz to 40 Mhz upstream), with optional support of mid-split (5Mhz to -120 Mhz upstream) and high-split (-800 Mhz to ~ 1GHz upstream); frequency reuse in the upstream channel; and co-existence with other home information appliances (e.g., entertainment TV) and other uses sharing the broadband system.

The detailed performance requirements for the MAC and for the PHY have yet to be specified by the P802.14 WG. The majority of the MAC proposals received by the working group will be put to modeling and simulation performance scrutiny with the initial results presented at the March, 1996 meeting.

The P802.14 work plan has been recently finalized, setting the stage for a completely draft work by the end of 1996. This section has attempted to summarize some of the aspects of the challenge faced by the P802.14 WG. At the time of this writing, the following additional issues will need to be resolved by the WG:

- Will Plain Old Telephone (POTS) be a fundamental service; i.e. DSO at 64 Kbps?
- Will ATM be selected as the Protocol Data Unit (PDU)?
- What Forward Error Correction (FEC) algorithm will be used and how much protection?
- If a slotted approach is used, what is the size of the slots?
- Where will complexity be placed in the system? Putting it where is easiest to fix/maintain implies the head-end.
- Many-to-one sharing of a single upstream channel using a slotted approach requires ranging of the home NIUs. How precise will the ranging be and how will it be performed?
- Will the WG specify a set of PHY profiles that may be used or just one downstream and one upstream PHY?
- How will provisioning of authorized stations be performed by the MAC protocol?
- How will the downstream and/or upstream channels be encrypted and how will keys be managed?
- How does the MAC protocol handle errors?
- How will stations will identified in the sub-network?

The above issues are continually being discussed in the P802.14 working group. As of this writing, the P802.14 Working Group has tentatively decided to select Quadrature Amplitude Modulation (QAM) 64 as a mandatory protocol for the downstream channel, The use of

QAM16 and QAM256 are for future study. The modulation technique for the upstream channel is currently under debate in the working group. There is a reasonably likelihood that Quadrature Phase Shift Keying (QPSK) will be one of the selected types due to its ability to perform better in a low signal to noise environment and that there is past industrial experience with this method. The specific choice(es) will be made during the March, 1996 meeting.

Expected Downstream and Upstream Data Channel Rates

For downstream, the QAM64 technique is a 6 bit per Hertz coding scheme which yields a raw data rate of approximately 30 Mbps in a North American 6 Mhz wide standard video channel (data + guard bands). With FEC and the effects of framing, the actual usable information data rate is approximately 27 Mbps. The usable bandwidth is shared amongst all cable modems for both user and management traffic. When ATM is used at the protocol unit, the useful user data rate, the ATM payload rate is 23.9 Mbps.

If the upstream modulation technique is QPSK. The raw channel rate will be anywhere from 1.5 to 3.0 Mbps with the specific rate selected in the near future by the IEEE P802.14 Working Group. For example, a raw rate of 2.56 Mbps can be placed in a 1.8 MHz bandwidth allocation. The upstream channel requires a longer preamble and more FEC as compared to the downstream channel. The requirements for sharing an upstream channel between multiple modems requires the use of a guard band (dead time) is needed between packet bursts. The information data rate a single upstream channel will be approximately 2.0 Mbps. It is expected that several upstream channels can be used with the single downstream channel. The head-end controller will *place* cable modems on the appropriate upstream channels to facilitate load balancing and robustness needs.

## An ATM Deplovment Example

An example of using ATM to provide a cable modem based residential Internet service is presented in this section.

Moving IP packets over ATM is straightforward. At the subscriber premises, the user network connection is the Ethernet 10BaseT twisted pair interface. At the home, this means services is delivered via IP over Ethernet. The cable modem must either perform a bridge-like service and transmit Ethernet frames over ATM, or it must terminal Ethernet at the cable modem (like an IP router) and transmit IP datagrams over ATM. Either of these models is support by an ATM based service. Figure 4 illustrates the

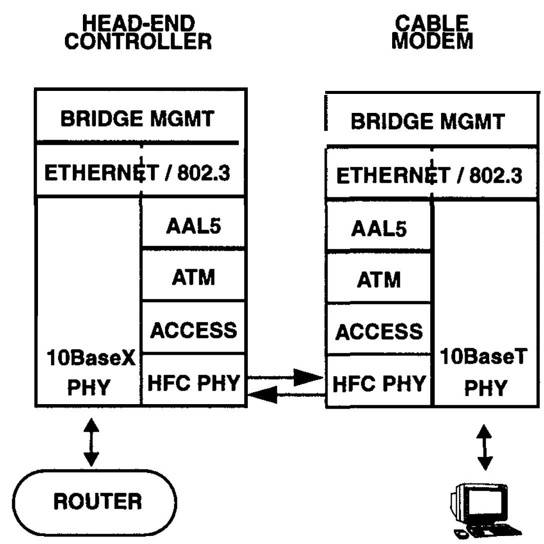


Figure 4. Bridged Ethernet via ATM Example

protocol stacks for a bridged Ethernet over ATM service. For IP directly over ATM, the protocol stacks would appear as illustrated in Figure 5.

The above two examples illustrate different mechanisms for moving Internet IP datagrams over ATM. It should be noted that moving other forms of integrated services, such as telephony is as straightforward. In fact, an ATM cable modem is capable of providing multiple service interfaces from the same box; e.g., an Ethernet

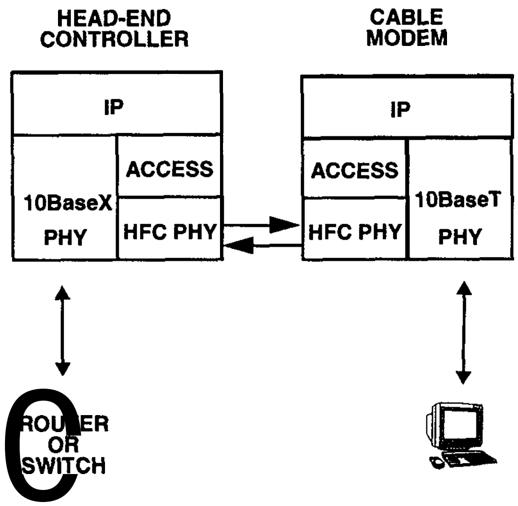


**Figure 5. Routed IP Example**

port for the home computer, and an RJ11 jack for the telephone. See Figure 6.

The multiple service capability of ATM is a very important consideration for deploying residential broadband services for three primary reasons:

Firstly, deploying ATM based cable modems for Internet services, allows a straightforward addition of future services without having to change out or install completely new additional equipment. That is, the cable modem box the supports Internet data can co-exist on the same downstream and upstream channels as a new cable modem that supports telephony.

Secondly, the ATM cable modems described in this paper operate at the electrical RF interfaces of a CATV network. This means that an all-coax CATV system can begin to deploy revenue bearing integrated services, starting with a small installation size, then growing the system for either data or voice services.

Thirdly, when the service needs of data and voice exceed the capacity of the system, only then must the network be upgraded to a Hybrid Fiber-Coax system. And then, HFC need only be deployed in those geographic areas where the service is required.

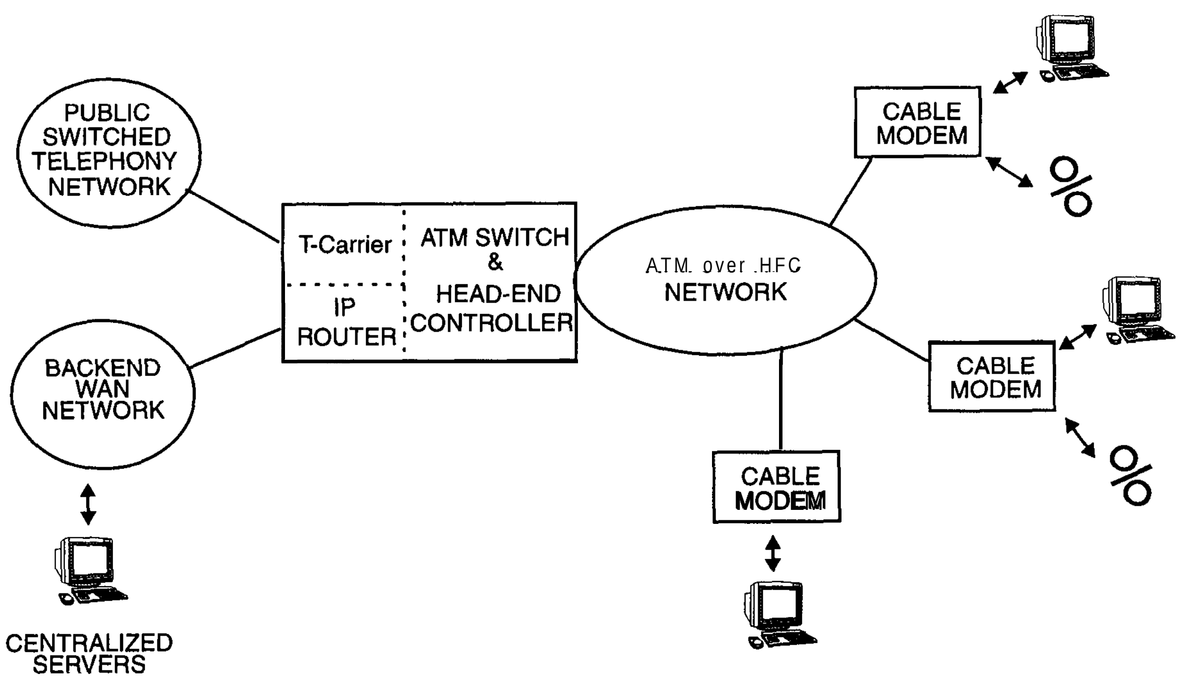


**Figure 6. Internet and Voice Deployment Model**

## SUMMARY

This article has presented an overview of the work in progress of the ATM Forum's Residential Broadband Working Group and that of the IEEE P802.14 Cable TV MAC and PHY Protocol standards Working Group. Initial review of these works is positive and indicate that ATM over HFC systems can be constructed using a MAC layer access approach.

The cable network environment will provide a very usable platform for delivering ATM-based Internet and voice services to and from the home. Actual deployment of ATM-based Internet to the home will occur in many areas of North America in the 1996 and 1997 time frame. Standards for ATM over HFC networks will appear in late 1997 at the earliest.

An ATM based integrated bearer service is well suited to allow a cable operator to install a system that will evolve in time and cost without significant duplication of up front investment,


## ACKNOWLEDGEMENTS

The author wishes to thank the participants of both the ATM Forum Residential Broadband Working Group and the IEEE P802.14 Cable TV MAC and PHY Working Group for their efforts to date.


## FOR MORE INFORMATION

Information on the IEEE's P802.14 Working Group can be found on the World Wide Web at:

http://www.com21.com/pages/ieee802.14.html

Information the Internet Engineering Task Force's IP over ATM Working Group can be found at:

http://www.com21.com/pages/ipatm.html

The ATM Forum is a closed industrial consortia and non-published work-in-progress documents cannot be distributed publicly to non-members. General information about the ATM Forum may be obtained from the Web at:

http://www.atmforum.com/

## REFERENCES


[1] ATM-FORUM, User Network *Interface (UNI) Specification Version 3.0*, ISBN 0-13-225863-3, Prentice Hall, December 1993.

[2] Kim, Albert, *Two- Way Plant Characterization*, Technical Session 23, National Cable Television Association Show and Conference, Dallas Texas, 9 May, 1995.

[3] Laubach, Mark, *Classical IP and ARP over ATM*, RFC1577, January, 1994.

[4] IEEE P802.14 Working Group, *Cable-TV Functional Requirements and Evaluation Criteria*, work in progress, IEEE802.14/94-002R2, IEEE 802 Committee, February, 1995.

l-51 IEEE, *IEEE Standards for Local Area Networks: Logical Link Control*, ANSI/IEEE Std 802.2-1985, Fifth Printing, Feb., 1988.

[6] Abramson, Norman, *Development of the ALOHANET*, IEEE Trans. on Information Theory, vol. IT-31, pp. 119-123, March, 1985.

[7] Roberts, L., *Extensions of Packet Communication Technology to a Hand Held Personal Terminal*, Proc. SJCC, pp. 295-269, 1986.

[8] Baran, Paul, *On Distributed Communication Networks*, IEEE Trans. on Communication Systems, vol. cs-12, pp. l-9, March, 1964.

[9] XEROX, *The Ethernet, A Local* Area *Network: Data Link Layer and Physical Layer Specification*, X3T5 1/80-50, Xerox Corporation, Stamford, CT., October 1980.

[10] IEEE, *Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications,* Standard 802.3-1985 (IS0 DIS 8802/3), IEEE, New York, ISBN 0-471-82749-5, 1985.

[1 1] Chelehemal, M., Prodan, R., et al., *Field Evaluation of Reverse-Band Channel Impairments,* Society of Cable Telecommunications Engineers, Emerging Technologies Conference, San Francisco, CA, 9-12 January, 1996.

[12] Laubach, Mark, *ATM For Your Internet - But When?,* ConneXions, Vo17, No 9, September, 1993.

[ 13] Atkinson, Ran, *Towards Real ATM Interoperability,* ConneXions, Vo17, No 8, August, 1993.

[ 14] Laubach, Mark, *IP over ATM and the Construction of High-Speed Subnet Backbones,* ConneXions, Vol 8, No 7, July, 1994.

[15] Clapp, G. and, Zeug, M. *Components of OSZ: Asynchronous Transfer Mode,* ConneXions, Vo16, No 4, April, 1992.

[16] Rybczynski, Tony, *The ATM Enterprise Network Switch: Enabler of Network Transformation,* ConneXions, Vol 9, No 11, November, 1995.

[ 17] Heinanen, Juha, *Multiprotocol Encapsulation over ATM,* RFC1483, March, 1993.

[18] Lucien, Rhodes, *The Race for More Bandwidth,* (Interview with Milo Medin of @Home), WIRED Magazine, 4.01, January, 1996, page 140.

## BIOGRAPHY

MARK LAUBACH holds a BEE. and M.Sc. from the University of Delaware. He is the Technical Ambassador and Chief Architect at Com21, Inc. in Mountain View California and responsible for the end-to-end systems architecture and ATM over HFC protocol specification of the Com21 product family. Prior to Com2 1, he was with the Hewlett-Packard Company for 14.5 years. Mark is a member of the IETF and is past chair of the IP-over-ATM Working Group. He is the author of RFC1577 *Classical IP and ARP Over ATM.* Additionally he attends the ATM FORUM and is the appointed liaison from the Forum's Residential Broadband Working Group to the IEEE P802.14 CATV MAC and PHY Protocol Working Group. He is a past member of the CSNET Executive Committee and a past member of the board of trustees for the Corporation for Research and Educational Networking (CREN = CSNET + BITNET).