An Evolutionary View of ATM Based Cable Television Residential Architectures

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ABSTRACT

As more services are transported digitally in the HFC network, an increasing number of them will be delivered via ATM (Asynchronous Transfer Mode) technology. At some point, after voice, video, and data are all carried digitally on the HFC network, all network transport will likely be via ATM. ATM, due to its efficient statistical multiplexing, guaranteed Quality of Service parameters, and unique adaptation layers for each type of service, is widely recognized as the best digital transport technology for the integrated delivery of voice, video, and data over a single network. In the evolution of the HFC network, ATM will likely migrate outward from the headend toward the subscriber, and ultimately into the subscriber's residence.

This paper looks at the integrated delivery of ATM based voice, video, and data services directly to the subscriber's home via an HFC network. An evolutionary examination of various residential CATV architectures which may be used to deliver ATM based services within the home and the technical and consumer issues and tradeoffs relating to each of these architectures is provided. The unique requirements imposed by ATM delivery and the unique opportunities afforded by ATM delivery are discussed. The evolution of service offerings made possible by such residential architectures is also examined.

INTRODUCTION

Competition to provide new services, ongoing deregulation of the telecommunications industry, competitive threats to existing services, migration from analog to digital signal delivery, and rapid growth of the internet and data services have dramatically changed the telecommunications landscape. CATV systems must in the near future provide a combination of analog television, compressed digital television, HDTV, telephony, data services, internet access, and numerous other interactive and multimedia services.

At the same time, there is an increasing economic incentive to integrate delivery of these services within the network itself, and ultimately to the subscriber. An integrated delivery system reduces maintenance and installation costs as well as capital equipment expenditures by transporting all services through common channels and equipment. At some point, it will no longer make sense to offer disparate services which share the HFC transport path but which essentially operate independently and use different headend and customer premise equipment, transmission formats, and signaling mechanisms.

For many reasons, true integration of service delivery throughout the network cannot be accomplished until all services are transported digitally. Television signals are still primarily analog on HFC networks, but over the next few years these signals will be displaced increasingly by compressed digital NTSC signals, which are already being carried in some systems. Many other services are already provided digitally or will be in the near future: CD quality audio, internet access, and telephony. Currently, these digital services are all operated independently on the network, sharing only a common RF distribution path in the HFC network. And in most cases these services are delivered without the benefit of modern packet switching, relying instead on more traditional frequency and time division multiplexing methods. However, growing competition, the ongoing migration of analog signals to digital transport, and the increasing need for integrated delivery of voice, video, and data services will ultimately drive HFC network transport toward a packet switched architecture.

Packet switched networks are more suitable for integrated service delivery than circuit switched networks. Packet networks use statistical multiplexing in the transport path and thus can greatly increase transmission bandwidth efficiency. These networks also provide bandwidth on demand to the subscriber without any network re-engineering, which gives the overall network much greater flexibility for providing new services and evolving gracefully. Using modern fast packet technologies, it will be possible to deliver voice, video, and data services directly to the home using a single, common delivery mechanism, possibly even over a single digital data stream.

Carrying voice, video, and data on the same network through the same digital pipes is not an easy task, however. Each of these services has unique transmission requirements. Data transmission tends to be bursty, but transmission delays can usually be tolerated. Television requires a lot of bandwidth to the home, but little or none back to the headend. Telephony requires symmetrical transmission, but will not tolerate long transmission delays. Data is somewhat tolerant of transmission errors because errored packets can be retransmitted, but voice signals do not allow retransmission of errored packets because the corrected audio packet would arrive too late to be placed in the proper speech sequence. A purely digital network delivering all these services must provide the mechanisms and flexibility to meet each of these unique transport requirements.

Of the fast packet technologies available today, only ATM (asynchronous transfer mode) was designed from the beginning to simultaneously support the unique transmission requirements of voice, video, and data. Unlike other packet technologies, ATM supports reserving network resources and defining a Quality of Service (QOS) for a transmission path when the connection is initially established. This is critical for delivering a diverse set of applications with a wide range of transmission requirements. Reserving network resources guarantees adequate bandwidth will be provided by the network to transport the service intended for the link. Defining the QOS for a link further tailors the network transport requirements specifically for the application to be transported. Typical QOS parameters include Cell Error Rate (CER), Cell Loss Ratio (CLR), Cell Transfer Delay (CTD), and Cell Delay Variation (CDV).

As ATM is introduced into the HFC network, it will most likely be used in the network backbone to connect headends or to route signals within headends. As the network evolves, ATM will migrate outward from the headend toward the subscriber. Early in the evolution, services will be offered to end-users via ATM on a service specific basis independently of other services. As more services are delivered to the subscriber via ATM, these will ultimately be integrated throughout the network through common ATM switching, signaling, and transport platforms. Only ATM can provide the flexibility, efficiency, and low cost necessary to integrate the delivery of voice, video, and data services throughout the network. However, for both technical and economic reasons such a network is still a future prospect. ATM will be deployed incrementally in the network, and services will be integrated on an evolutionary basis as hardware becomes available and economic factors allow. Of course, network management becomes much more critical in this system for operations, administration, maintenance, and provisioning, and extensive software support systems must be deployed in parallel with the ATM transport hardware.

ATM TRANSPORT

ATM transport is accomplished with fixed length cells, each cell being 53 bytes long. Of these 53 bytes, 5 are used for the header, and 48 are used for the user information field. The header is strictly used for network transport functions such as destination routing, error detection, and cell delineation. The user information field is used for carrying service specific information and the application payload. Once created, ATM cells are time division multiplexed onto the appropriate transmission channel for routing to their final destination. As cells travel through the network, they may encounter additional switching nodes, at which point they will be switched to the appropriate channel and on toward their final destination.

ATM is a connection-oriented packet transmission protocol. As the name implies, connection-oriented networks require that a logical connection be established between two endpoints before data may be transferred between them. These connections are made via virtual circuits and require setup operations to establish each connection, its routing path, service class, QOS, and bandwidth. The term 'virtual circuit' simply means such a channel appears to the end-user just as a real circuit connecting the two end points. Several virtual circuits (and their ATM cells) can share the same physical channel between two points in the network.

On an HFC network, the physical channels are actually RF channels which are frequency division multiplexed across the upstream and downstream spectrums of the network. Transport may be over fiber or coax. The ATM cells themselves are time division multiplexed onto these RF channels, but with no inherent knowledge that RF transport or a particular modulation method is being used. RF transport simply serves as the physical transport layer in the distribution portion of the network.

The fully integrated ATM network must be capable of delivering all services via virtual connections and with unique content to each home. Such a network will truly allow the subscriber to select services and content on demand. Frequency division multiplexing of RF channels in the network and time division multiplexing of virtual circuits within each RF channel allow flexible coupling of services with RF channels and virtual circuits. For example, it becomes possible to put all services for a single home onto a single RF transport channel, with each service using a different virtual circuit within that RF channel. This allows only a single RF receiver to be used in the subscriber home to recover all services that subscriber takes. When a subscriber is not using any of these services, he need not be allocated any RF spectrum, and this unused spectrum may then be allocated to another subscriber. It may even be possible at some point to use a scaleable bandwidth RF transmission system that occupies only enough spectrum to transmit the services currently being used by an individual subscriber.

Taking the opposite approach, individual RF channels may be dedicated to single services. In this case, for example, a single RF channel could be used to deliver digital audio services, with each active subscriber assigned a separate virtual circuit on that channel to receive the specific music he has selected. This would typically require a separate receiver for each service the subscriber takes. Of course, when a subscriber is not using a service, no virtual circuit or bandwidth need be allocated to that subscriber, thus allowing the unused bandwidth to be allocated where it is needed. For broadcast type music services, several subscribers would simply "listen" to the same virtual circuit, much as they might tune to the same radio station.

In a similar fashion, the return path may be handled by a single residential upstream transmitter supporting several upstream services, each service being assigned its own upstream virtual circuit. Or the return path may be handled with several service specific upstream transmitters, each assigned a unique frequency or time slot on the same frequency. In either case, upstream transport will become increasingly necessary in an integrated network, not only for bi-directional services such as telephony, but for provisioning, status monitoring, maintenance, and customer interaction.

Given the technical complexities of operating an integrated on-demand network, a robust mechanism for spectrum and virtual circuit management will be essential. The way services and virtual circuits are assigned to RF channels in the HFC network, both upstream and down, will also place economic and technical limitations on the ways residential architectures may be realized.

HFC ATM RESIDENTIAL CATV ARCHITECTURES

The following discussion assumes that the HFC network has evolved to the point that one or more services are delivered to (and possibly from) the home via ATM over RF channels. In the downstream direction, the RF signals must at some point be converted to baseband digital signals for recovery of the virtual circuits and the ATM cells they contain, and possibly for further routing within the network or subscriber's home. The opposite is true in the case of upstream signals. For both the up and downstream directions, the residential CATV architecture will determine how and where these RF conversions will take place and how signals will be distributed within the home. This architecture may take several forms, but will likely follow an evolutionary sequence determined by economics, home wiring issues, service offerings, and consumer electronic equipment. Of the myriad number of possible residential architectures, three basic approaches are outlined below to explore potential residential issues and solutions.

Even without ATM, today's residential delivery system already poses some of the most daunting challenges to providing new, reliable, and cost-effective services: powering residential equipment from the network vs. the home, interfacing with existing consumer electronics, and addressing residential wiring issues such as return path ingress. These challenges will only increase as the HFC network migrates toward ATM and as service offerings and consumer electronics become technically more complex. Open interface and transmission standards for both network equipment and consumer electronics will be essential to the success of any integrated service delivery system.

Service Specific ATM Interface Architecture

Initially, ATM will make its way to the residence over a single service. The likely first candidate is an ATM based cable modem for internet access. Since internet access is not a lifeline service (at least not today), powering from the network is not an issue, and this device will be powered by 120 VAC as other residential electronic devices. Similarly, the cable modem will provide a standard RF interface to the cable system (via an F connector) and another standard data interface to the computer (most likely ethernet or ATM). Because the modem bridges together a network and network device that traditionally in the past

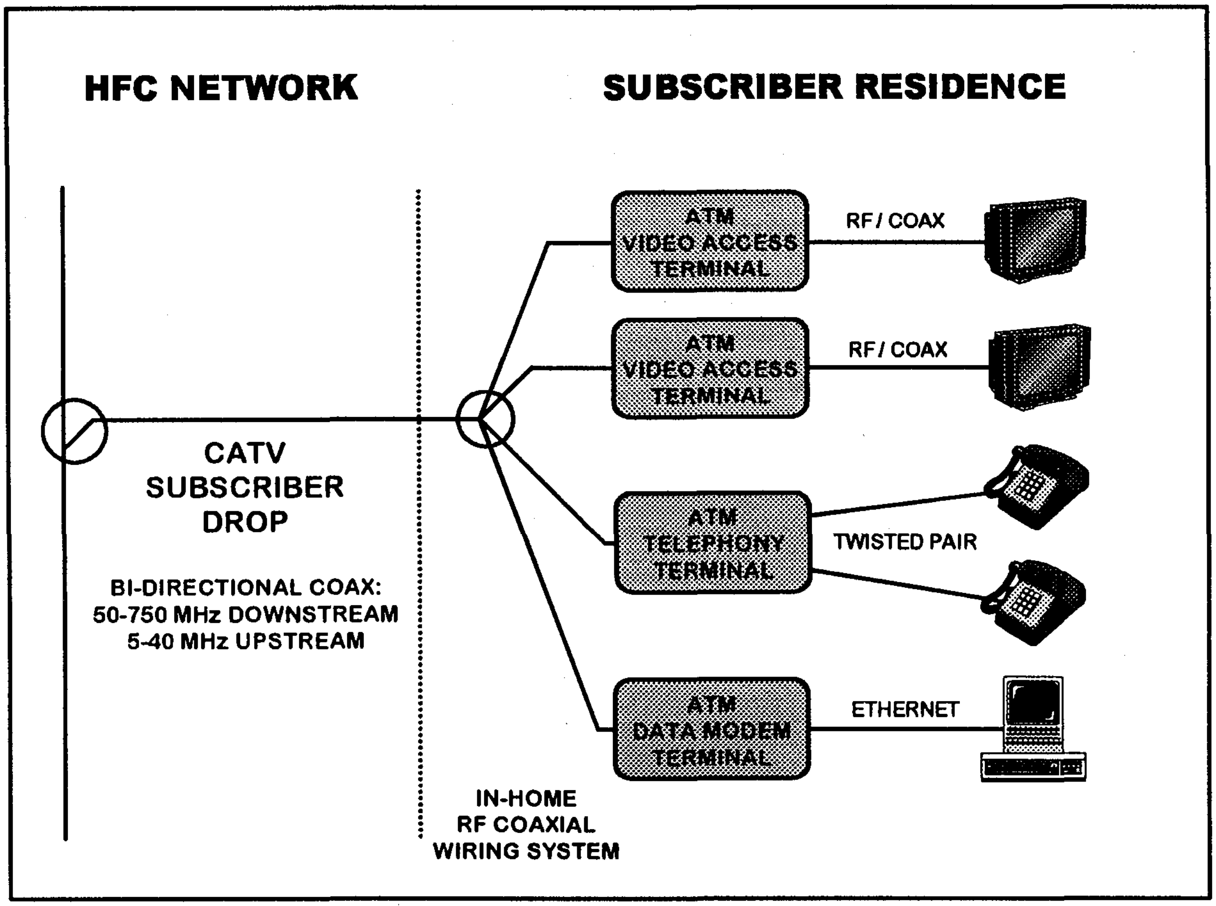

Figure 1 -- Service Specific ATM Architecture

had no interaction, the modem will likely be a standalone device, though versions can easily be made which plug into the computer.

There is also a desire to keep installation costs to a minimum, so it is very undesirable to make significant changes to the existing home wiring. Since many homes are already wired for CATV distribution, but very few for ethernet, signal distribution in the residence for the modem service will be via RF over the existing home CATV wiring or extensions of it. This means the cable modem will typically be located next to the computer it serves, with only a short data interface cable running between the modem and computer.

As the evolution of the HFC network proceeds, more services will begin to be delivered to the subscriber via ATM. A second likely service for ATM delivery to the home is compressed digital NTSC, which can take advantage of the full switching capabilities of ATM to deliver true video on demand. Other services will follow, including basic telephony, and this will probably occur on a service by service basis. Of course, each of these new services will impose new requirements on the residential architecture and wiring. For example, telephony will require that powering issues be resolved to ensure that phone service remains available even during power failures at the residence. Figure 1 depicts a residential architecture based upon specific interface devices for each service.

Because ATM deployment will be incremental and because not all subscribers take all services, it is likely that a specific RF / ATM interface device (sort of an ATM set-top converter) will initially be required for each new service delivered via ATM. Of course, the logical evolution would be for these interface functions to migrate into the consumer electronic devices themselves, and this may very well happen if issues such as open standards, signal security, and feature enhancement can be worked out between the CATV and consumer electronics industries. But there will be a long period of time in which it will be necessary to support legacy consumer electronic products with outboard interface devices, just as we have for years with RF set-top converters. If open standards can be developed for such ATM interface devices, it should be possible for consumers to buy them at the local electronics store.

Regardless of the service being supplied, each ATM interface device must maintain those virtual circuits (if more than one is required) associated with its particular service at this particular residence. Since each service requires a unique ATM access device, this architecture can be considered to be distributed. For some services, such as television, it may be necessary to have an interface device for each consumer device connected to the network (much as is the case today with set top converters). For other services, such as telephony, a single ATM interface device may serve several consumer devices in the home. Because this residential architecture is distributed, an RF receiver will be required in each interface device in the home, and in the case where return transmission is also required, each device must have an upstream transmitter.

ATM Residential Gateway Architecture

Another approach to residential access is the residential gateway, which is shown pictorially in Figure 2. The residential gateway is an integrated access device providing a single interface to the HFC network and multiple service interfaces to the home. In all likelihood, the gateway will consist of a small chassis which accepts plug-in modules. Such an approach allows modules to be installed only when actually needed to provide service and supports ongoing upgrades and evolution of the platform as a whole. The residential gateway architecture can easily accommodate existing consumer electronic devices through standard interfaces but will also support future consumer devices and their interfaces through new service interface modules.

The gateway may be owned by the service provider or by the subscriber, or by both. In this last case, the service provider may own the chassis and common equipment which is critical for service delivery, signal security, and other functions. The subscriber might then provide plug-ins for specific services he subscribes to. As such, the residential gateway could function as a standardized network interface for the home while providing a demarcation point between the network and customer premise equipment. One great advantage of the residential gateway is that it can provide operator controlled access to the HFC network, which eliminates system ingress caused by residential wiring systems or consumer electronic equipment.

Using a non-distributed architecture, the residential gateway also offers the advantage of allowing common equipment to be used to support several services. For example, since all services are fed from this single chassis, a single power supply can be used for all service interface devices in the box. Similarly, a single RF transmitter can be used for all services requiring upstream transport. The residential gateway also supports migration of services to ATM on a service by service basis simply by plugging new cards into the residential gateway. As pointed out earlier, ATM deployment will be incremental. The residential gateway should provide a lower cost solution to delivering ATM services when compared to using multiple

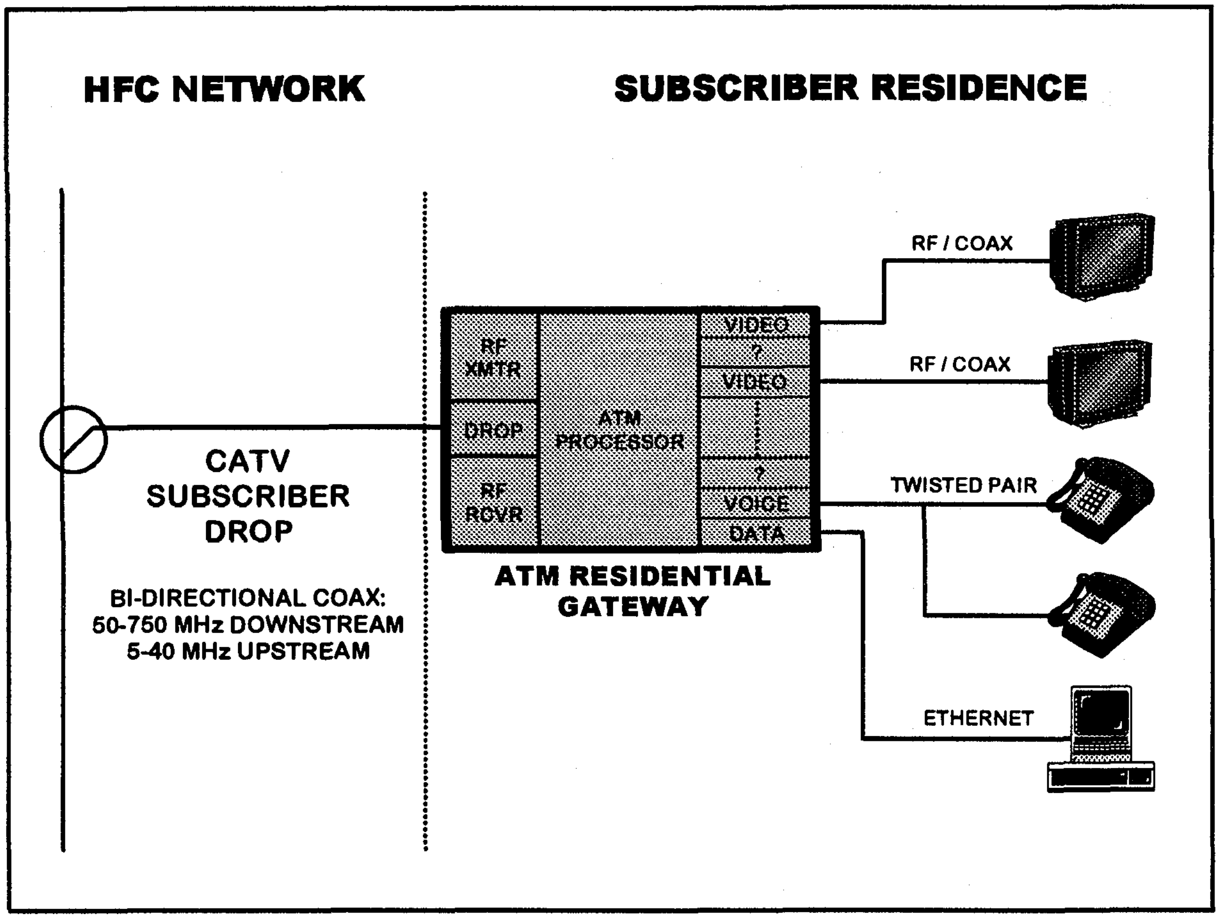

Figure 2 -- ATM Residential Gateway Architecture

service specific access devices, but more careful planning must go into the design of the gateway to ensure flexibility as services and the residential architecture evolve.

From an evolutionary perspective, the residential gateway addresses several of the concerns already discussed above under service specific interface devices, but without using a distributed architecture. Several architectures exist for the residential gateway itself. In the example shown here, a single RF receiver interfaces with the subscriber drop, then demodulates the high speed RF data stream. This stream is then fed to an ATM processor which maintains each of the virtual circuits associated with this particular residence. Several virtual circuits are present in this one data stream. Some of these virtual circuits may be intended for other residences, and these ATM cells are discarded by the local ATM processor. For those virtual circuits intended for this home, the ATM processor delineates which service is associated with each virtual circuit and forwards the ATM cells for each virtual circuit to the correct service interface module.

In all likelihood, these virtual circuits will be a combination of permanent virtual circuits (used for continuously connected services) and switched virtual circuits (used for sporadic or demand based services). Some of these virtual circuits will not be associated with services, but with performing other local functions such as status monitoring and provisioning of the gateway as a whole. Each service interface module is responsible for converting its virtual circuits to electrical signals which can be distributed independently through the residence and then used directly by the subscriber's TV, telephone, computer, etc. In many cases, the existing home wiring can be used for this final distribution.

The reverse path operates in much the same way. Each service interface module formats its return data as ATM cells then forwards the virtual circuit containing these cells to the ATM processor. The ATM processor then time division multiplexes all these virtual circuits onto a single data stream which is fed to the upstream RF transmitter. Again, the upstream path will likely contain both permanent and switched virtual circuits, and one or more of these will be dedicated for maintenance and provisioning of the gateway itself. Not all services will require an upstream connection.

ATM Residential LAN Architecture

One common component in the residential gateway, the ATM processor, may at some point also begin to assume significant additional functions. Since all virtual circuits for all services in the home flow through the ATM processor, the processor may assume switching functions local to the residence itself. Local virtual circuits between consumer devices could be supported, and this would allow consumer electronic devices within the home to communicate with each other and exchange signals, services, and information. For instance, a VCR in one room might provide video via the gateway to a television set in another room. Or computers within the home could exchange files or other information through the gateway.

An early version of such a residential gateway LAN could evolve from the architecture discussed above and could support existing consumer electronic devices over their standard interfaces. However, because most of today's consumer products were not meant to intelligently interact with one another, only limited capabilities can be realized with this approach. Any intelligence in such a LAN would reside primarily in the gateway itself and would be transparent to the devices connected to it (with the exception of home computers, of course).

As service offerings, consumer electronics, and the network further evolve, increased functionality and interoperability will spread throughout the residential architecture and its consumer devices. In the long view, the residential ATM interfaces will likely migrate from the residential gateway into the application device being served, whether it be a computer, telephone, TV set, thermostat, or garage door opener. Once this occurs, the residential gateway will serve as both a local ATM switch for the home LAN and as the HFC ATM network gateway.

Figure 3 shows how such an ATM LAN may serve the residence. In this example, all home devices are connected to the gateway LAN via home runs on shielded twisted pair running 100 Mb/s ethernet. All devices maintain bi-directional communications with the LAN gateway both for service content and for configuration information. Devices may either communicate with each other or the HFC network, but all communications must flow through and be switched by the gateway LAN. All communications in this example are still via ATM, but through cells transported over ethernet. Other residential architectures could be derived which provide similar functionality. For instance, the home wiring could be structured around a bus architecture, where the home devices could communicate directly with each other.

The residential LAN allows great simplification of home wiring. Since all devices in the home would be served off an identical digital interface, only one home wiring system may be required for all residential devices. One could just as

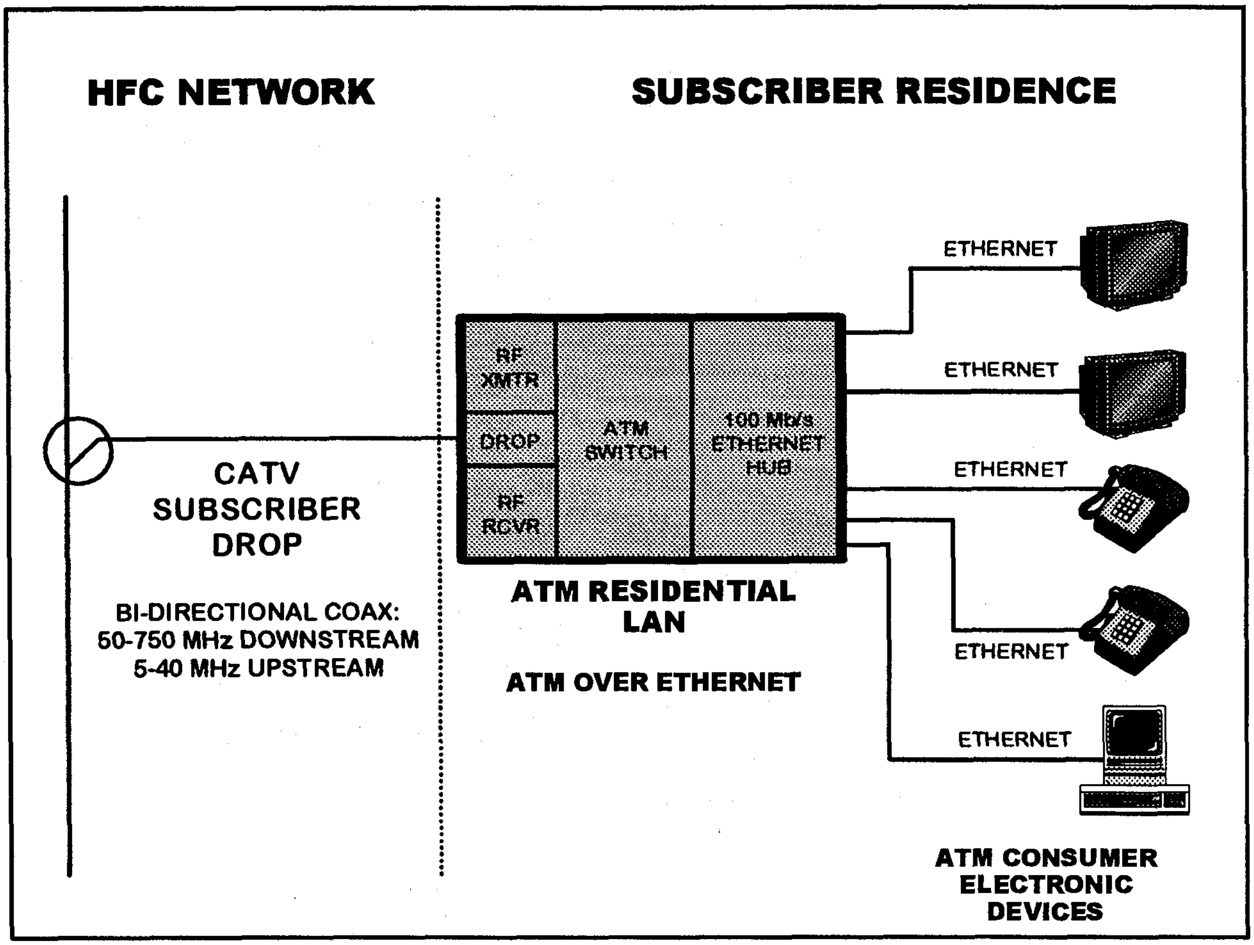

Figure 3 -- ATM Residential LAN Architecture

easily plug a computer or a television into the same outlet in any room in the house. In fact, a single connector could be used for both the LAN digital interface and for powering the local device.

Many transport technologies exist for creating LAN's: twisted pair, fiber, coax, etc. And many protocols exist for creating LAN's: FDDI, ethernet, token ring, etc. The ATM LAN discussed here is too far into the future to predict which residential transport technology or protocol will prevail or even exist when the time comes to build such a LAN. But it is obvious that such an ATM LAN cannot exist without rigorously defined open standards for hardware vendors to build their products around.

SUMMARY AND CONCLUSIONS

Analog signals will continue to disappear from HFC networks as digital delivery of traditional services becomes more common and as new digital services are offered. Digital signals not only offer better service quality, but can offer other benefits such as better spectrum utilization. As the migration toward an all digital network continues, it will eventually make sense to transport these digital signals over an integrated delivery platform. ATM is the best technology for integrating and delivering voice, video, and data services over a single digital network. Operational, economic, and competitive considerations will drive the deployment of ATM in HFC networks. Initially, ATM will be used in HFC systems for backbone transport. But as services, technology, and the competitive environment evolve, ATM transport will migrate over the HFC network toward the subscribers' home, where ATM's full capability will be realized as new service offerings and applications are made possible. It is in the subscriber's home, however, that some of the most daunting challenges exist for fully digital, integrated delivery of services directly to the subscriber. Issues such as powering, legacy consumer products, home wiring, and new applications must be addressed if the full capabilities of an integrated network are to be realized.

New services will also be made possible or economical by ATM technology, and these too will be integrated into the network as it evolves. ATM's switching capability opens up many possibilities for economically delivering local ad-inserts or video-on-demand services from a single, centralized video file server center. As the ATM switching capability extends to individual subscribers, TV ads may literally be targeted to individual homes--in fact, you may be able to choose your own ads! Some day all television viewing may be video-on-demand operating over virtual channels, but this will be transparent to the subscriber, who only knows that he can watch whatever he wants whenever he wants.

REFERENCES

Black, Uyless, *Data Link Protocols*, PTR Prentice Hall, Englewood Cliffs, NJ, 1993.

Black, Uyless, *Emerging Communications Technologies*, PTR Prentice Hall, Englewood Cliffs, NJ, 1994.

Hart, Gaylord, "Architectural Considerations for Overlaying Fast-Packet Networks on Hybrid Fiber/Coax Systems," *NCTA 1996 Technical Papers: Proceedings of the 45th Annual Convention and International Exposition of the National Cable Television Association*, pp. 360-374, NCTA, Washington, D.C., 1996.

Hart, Gaylord, "Deploying ATM in Advanced HFC Networks," Communications Technology, December 1996, Vol. 13, No. 10, pp. 34-51.

Kessler, Gary C., *ISDN: Concepts, Facilities, and Services*, 2nd Edition, McGraw-Hill, Inc., New York, NY, 1993.

Onvural, Raif O., *Asynchronous Transfer Mode Networks: Performance Issues*, 2nd edition, Artech House, Norwood, MA, 1995.

Spohn, Darren L., *Data Network Design*, McGraw-Hill, Inc., New York, NY, 1993.

Stallings, William, *ISDN and Broadband ISDN with Frame Relay and ATM*, 3rd Edition, Prentice Hall, Englewood Cliffs, NJ, 1995.