Residential Gateways in Full Service Access Networks

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Abstract. Recent advances in access technologies are creating several new network elements that enable the delivery of multiple services over high bandwidth access streams. However these advances are often slowed by the substantial amount of legacy networks and systems, as well as by the lack of a unifying end-to-end architectural vision. This paper presents our view of the evolution of the network to an "interconnection network" supporting connectivity to diverse end-to-end services using varied access methods. We emphasize the importance of a Residential Gateway to support emerging access technologies, legacy home networks, and new home network technologies in a seamless, modular way. An architecture for an interconnection network, including a low cost modular Residential Gateway, is presented. The architecture provides a framework for supporting self-configuring "plug and play" network elements that provide dynamic access to multiple services.

Keywords: residential gateway, access network, broadband access, optics, network architecture, home controller.

1. Introduction

Traditional access methods, which rely on twisted copper pairs for POTS (Plain Old Telephone Service) or coaxial cable for analog television service, are steadily evolving to a diverse collection of technologies that are capable of providing two-way broadband access to the residence. This new capability presents both an opportunity and a challenge to the access provider. The opportunity arises in the ability to deliver many new services to the customer, while the challenge resides in the necessity of delivering these services economically.

High-speed access is evolving from ISDN data rates, to xDSL data rates that range from 1.5 megabits per second to 50 megabits per second, to fiber-to-the-home rates that can be in the hundreds of megabits. Support for broadband access to the home must be able to accommodate new features and services as they develop without rendering the home infrastructure obsolete.

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Therefore, a modular solution is required, where access interfaces can be updated without disabling (or even powering down) feature interfaces, and new feature interfaces can be added without requiring a new access infrastructure.

The *Residential Gateway* (RG) is a box that sits in a remote location in the house where it is unlikely to be disturbed by household activity. The RG allows hot insertion of plug-in *Feature Cards* for both access and in-home services. Once a Residential Gateway is installed, it enables access to a variety of traditional and emerging services, and protects both the access provider and the consumer from obsolescence.

Some have suggested using a cable TV set-top box or a PC as a Residential Gateway. Neither of these solutions are optimal. A set-top box is optimized for cable television and is not easily extensible to general purpose networks. A standard PC, while more flexible, does not handle real-time data. PCs are noisy, somewhat unreliable, and apt to be powered off. PC buses do not support hot insertion; therefore, cards cannot be installed without powering down the PC. Indeed, most consumers are reluctant to install new cards in their PCs. An additional complicating factor is that PC and set-top boxes are poorly located to serve as wiring hubs

2. Access Infrastructure for Residential Gateways

As seen in Figure 1, the Residential Gateway multiplexes data from different in-home networks, such as POTS or IP (Internet Protocol), onto a single broadband trunk. Each service in the home is connected by a "virtual wire" to its respective service provider. These virtual wires are multiplexed by the RG onto a single access trunk to the Access Network where they are routed to their respective service providers.

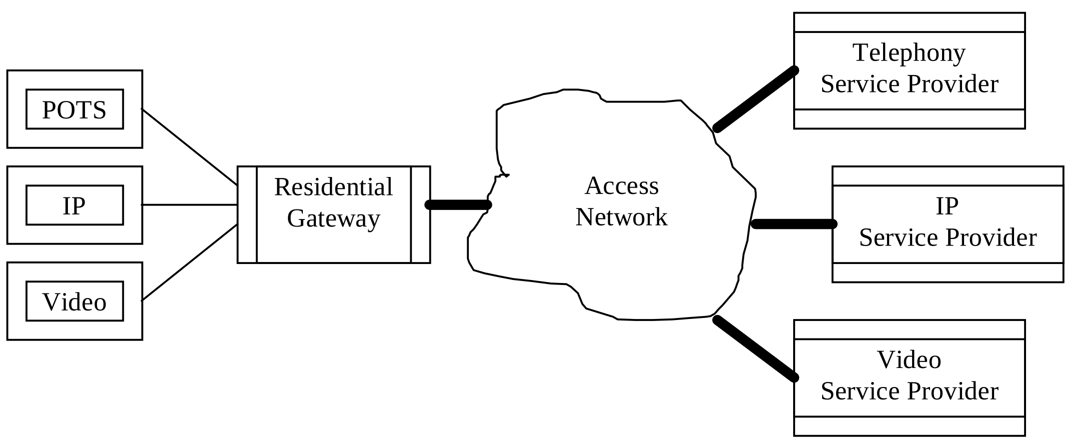

Figure 1.

The Access Network need not know the content of any of the data streams it is carrying, as long as it can guarantee connections with a suitable Quality of Service (QoS). Only the Feature Cards in the RG and the corresponding equipment at the service provider's site know the details of the service's protocol. This independence of data transport from content means that new services can be added without redesigning the network. A single interconnection mechanism allows simpler network design and a simpler architecture for adding new services. It is more reliable and easier to maintain.

Asynchronous Transfer Mode (ATM) is the preferred transport mechanism for Access Networks, since ATM provides reliable connections between endpoints with a guaranteed QoS. A single connection mechanism is used for all services. Each "virtual wire" from a service provider to a home network is implemented as an ATM virtual circuit. All traffic between the provider and the residence is carried transparently over these virtual wires, which are created dynamically as ATM switched virtual circuits (SVCs). Both connection oriented and connectionless services are supported over this unified connection model. IP service is implemented in this model by creating a virtual wire from an in home IP network to a router in the service provider's network. ATM also has the advantage that suitable hardware is available to build cost-effective switches.

3. Protocols

All communication systems depend upon a variety of protocols. Standard ATM protocols are used to provide connections, supplemented by other protocols used to maintain the Access Network.

3.1 Addressing

The link management protocol distributes addresses to all nodes in the Access Network, including all Feature Cards within each RG, and maintains the addresses in the event of a network topology change. All endpoints are in a single address space, so connections can be made anywhere in the Access Network. Addresses reflect Access Network topology, and are designed to aid routing. Therefore, addresses can change as the network evolves. These addresses are private to the Access Network and are not visible to either residential customers or service providers.

3.2 Naming

The Access Network provides a name service protocol for mapping names to Access Network addresses. Names are symbolic identifiers of nodes, which do not change when the network topology changes. Every service provider in the network has a name, which is maintained by the Access Network provider. These names can be for specific services (such as "Pat's IP Service") or generic (such as "voice telephony").

Services maintain their own name space, separate from the Access Network name space. A telephony service, for example, maintains the telephone number name space of its clients. An Internet Service Provider (ISP) maintains a name space of IP numbers. These service name spaces are independent and service-specific. Service applications only need to know the name service protocol for handling their own name space.

4. Components of the Infrastructure

The network is comprised of *Residential Gateways* (RGs) on the customer premises, *Service Gateways* (SGs) to provide connectivity to service providers, and *Access Gateways* (AGs) to manage connection of RGs to the Access Network. The RG terminates the various in-home networks, originates ATM connections across the Access Network to the SG, and transfers data between the in-home network and the Access Network. The SG terminates the connection to the service provider, receives ATM connection requests from the Access Network, and transfers data between the Access Network and the service provider. The AG terminates the access method and controls the ability of the RG to enter and use the Access Network. The connections between the Access Gateways and the Service Gateways can be short links inside a central office, or they can extend across a metropolitan or wide-area ATM network. These components are illustrated in Figure 2.

The next-generation Access Network grows from one where broadband service is available only in a single central office to a general ATM Interconnection Network without requiring the replacement of the access infrastructure.

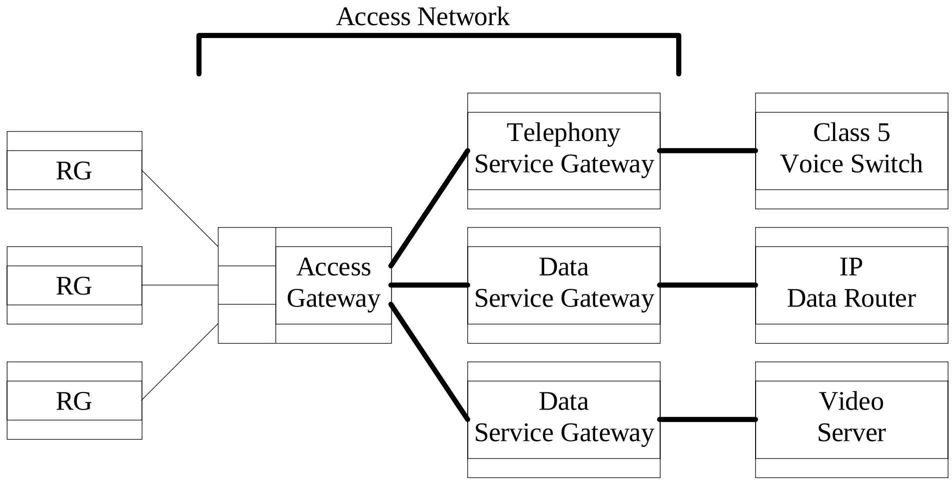

Figure 2

4.1 Residential Gateway

The Residential Gateway terminates the access connection and delivers a data stream to each of the networks providing service inside the home. In addition to protocol conversion, the gateway functions as the head-end for in-home networks, providing applications, network management, and other features. Functions of the RG include:

- Auto-configuration, so that a user who either does not wish to configure or does not feel capable of configuring a network is not required to do so.
- Hot insertion, so that installing a new feature does not affect the current operation of the gateway.
- Switch port isolation, so that malfunctioning or "rogue" cards do not affect the performance of the gateway.
- Sufficient bandwidth, to evolve from medium speed networks like ADSL to future very high speed networks like Fiber to the Home (FTTH).
- Feature Card independence, so that performance does not degrade as new features are installed.

The ideal configuration for the gateway is a switch, rather than a shared-memory bus. Although buses like PCI have ample peak bandwidth, the peak bandwidth available degrades as more short messages are transferred. Hot insertion requires extra hardware to protect the bus from unstable signals that arise when power is coming up on a newly-inserted board. Similarly, it is difficult to protect the bus from a board that is dumping data indiscriminately and completely consuming the bus bandwidth. Mechanisms are also required to prevent one card from consuming all of the shared memory buffer space.

A switch-based design, on the other hand, avoids the difficulties present in a bus-based design. Since all connections in a switch-based solution are point-to-point, the only design difficulty for hot insertion is power supply loading which is easily solved with passive components. Unidirectional point-to-point connections in switch-based designs require fewer signals than bus-based designs, and allow for smaller, cheaper connectors. Because each port in a switch is independent, the bandwidth consumed by one card does not affect the bandwidth available to another card, so a rogue card cannot bring down the gateway. Both bandwidth and processing are shared in a bus-based design, while bandwidth is allocated per port and processing is distributed in a switch-based design. With a switch-based design each card's processing capabilities can be tailored to the application's requirements.

Our residential gateway is implemented as an eight port ATM switch. Each port of the switch fabric is capable of 155 Mb/s, yielding a total aggregate bandwidth of 1.24 Gb/s. The motherboard contains the switch fabric and a microcontroller connected to one of the switch ports. This microcontroller responds to ATM signaling messages and is responsible for setting up and tearing down connections in the switch fabric. The remaining ports are presented on connectors for plugging in modular feature cards. With current levels of integration an ATM switch is compact and economical.

For robustness, the switch controller only manages ATM connections. All content specific processing is relegated to feature cards. As additional feature cards are plugged into the RG, the switch controller only has to handle the increased signaling traffic. This separation of functionality provides a clean feature card interface to the RG and allows the switch controller to do a better job of managing ATM connections.

4.1.1 Residential Gateway Protocols

The switch controller manages the RG via four basic protocols. These protocols are carried on well defined virtual channels. Other virtual channels are dynamically allocated through ATM signaling requests.

The first protocol, In-band Configuration, is used by the switch controller to determine the type of feature card in each slot and perform low-level configuration. After configuration, the switch controller uses the IBC protocol to gather performance statistics periodically from each access card. IBC is a single cell protocol that is simple enough to implement in hardware for those feature cards not otherwise requiring an on-board processor.

The second protocol is the Link Management Interface. LMI performs initialization of the ATM link between the RG and feature card. The switch controller uses LMI to assign an ATM End System Address, or AESA, to each feature card. These AESAs are sub-addresses of the RG's own AESA. This hierarchical address assignment allows for simple routing algorithms. The RG itself gets an AESA from the Access Gateway described in following section. LMI also provides for the discovery and/or negotiation of important parameters at link initialization, such as bandwidth capability and VCI range. This information is used by the switch controller's call admission policy in setting up virtual circuits passing over the link. Another useful service of the LMI protocol is a keep-alive status message sent periodically to keep track of the (potentially changing) link status.

The third protocol is an Access Name Service, or ANS. The ANS maps humanly readable names into 20-byte AESAs. The network offers this service through the RG to feature cards. A name server allows the access network service provider to change its topology and hence its addresses without affecting their customers' service. This indirection also allows different distribution of services depending on geographical location. Residential gateways at different locations in a metropolitan area could be directed to different Service Gateways if local network name servers maintain different mappings, much as toll-free long distance numbers today can be mapped differently depending on the source of the call.

The last protocol is ATM Forum's UNI signaling. A feature card is capable of requesting switched virtual circuits, or SVCs, after it has acquired an AESA via the LMI protocol.

Hierarchical address assignment simplifies the routing of connection requests. If the destination AESA is not a recognizable sub-address of the RG, it is not local and the connection request is routed up to the access network. Using a standard UNI allows feature cards to specify a connection request and destination AESA not only to the switch controller, but also through it to the extended ATM access network.

As illustrated in Figure 3, service features are implemented in the RG by plugging Feature Cards into the switch. A feature card either terminates the ATM connection and interfaces with a particular in-home network, or passes the ATM cells through a particular physical access method and provides a link to the access network. The switch is symmetric; therefore, there are no reserved slots, and any card can occupy any slot. Software in the RG determines the configuration dynamically. For example, adding video to a configuration with voice and data involves plugging in a video feature card and connecting the video appliance (TV) to that feature card. Likewise, to evolve to a new access method, the old access card is removed and a new one installed, without disturbing the configuration of the service-oriented cards in the gateway.

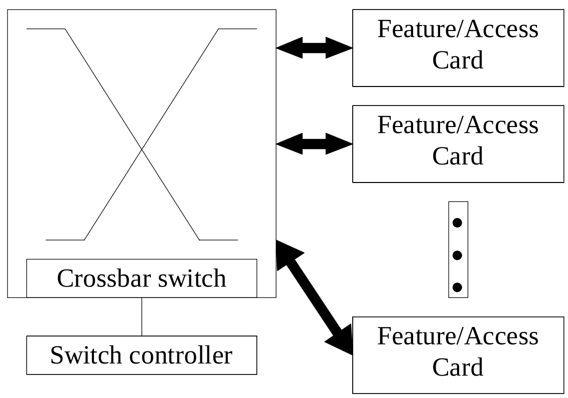

Figure 3

4.1.2 Feature Cards

Consumers can add new features by inserting a feature card. The consumer is not required to enter any configuration parameters or set any switches. To provide this plug and play operation, each feature card is equipped by the manufacturer with two values stored in non-volatile memory. The first is a unique identifier which specifies the manufacturer, card type, and serial number of the feature card. The second is an ASCII string specifying the default service provider's name. After a feature card is first plugged into the RG and acquires an AESA via the LMI protocol, it uses the service provider's name to query the ANS for the AESA of the service provider. A connection request of the required quality of service and bandwidth to that AESA is then made via the UNI protocol. Upon successful completion of the connection request, the feature card is provided a virtual circuit over which it can communicate directly with the service provider without RG or access network involvement. The RG and access networks simply pass ATM cells and maintain the quality of service contract. At this point, the feature card uses its serial number to uniquely identify itself with the service provider.

Examples of access feature cards include: xDSL over twisted copper pairs, fiber to the home, fixed wireless loop, and satellite downlinks. Such access cards only participate in the

IBC protocol. The switch controller uses the other protocols to communicate through the access card to agents on the remote end of the access link.

Examples of feature cards providing a service include: derived POTS lines, cordless telephone base stations, derived ISDN lines, MPEG video decoders, IP service over 10BaseT Ethernet, IEEE 1394 Firewire interfaces, home automation via CEBus, and home security interfaces. These feature cards implement protocol conversion between the ATM data stream and the service provided. For example, a POTS feature card converts periodically arriving ATM cells into a steady stream of 8-bit PCM voice samples to drive a speaker in one direction and collects 8-bit PCM voice samples from the microphone to be sent in an ATM cell in the other direction.

4.2 Access Gateway

An Access Gateway terminates an access method and provides control over access to, and use of, the Access Network. Although one of the advantages of the RG is the ability to insert Feature Cards in "live" and avoid a service call, this "openness" requires the network to protect itself from possible fraudulent uses. The AG provides this functionality. In addition, the AG identifies customers and ensures that their billing is up to date before allowing them to use the Access Network. The AG can optionally meter the amount of bandwidth delivered to the customer if bandwidth utilization is controlled, and keep track of connect time or cell counts if charging is to be done by usage. The functions of an Access Gateway include:

- Authentication, authorization and accounting for clients of the Access Network.
- Access Network address assignment to support auto-configuration of Residential Gateways.
- Call admission control to manage the resources of the Access Network.

In order to provide admission control for its clients, the Access Gateway must have access to account records. These are maintained in an Authentication Server. When a Residential Gateway announces itself to the network, the Access Gateway places a call to the Authentication Server which returns a record detailing the services available to that customer. The customer is identified by a unique identifier built into the access interface on the Residential Gateway. This identifier is protected by a cryptographic exchange to prevent snooping and subsequent theft of service. This mechanism is similar to the user locator servers used in a cellular telephone network.

4.3 Service Gateway

A Service Gateway provides connectivity between the Access Network and a service provider. The functions of the Service Gateway include:

- Authentication, authorization and accounting for clients of the service. The Service Gateway verifies that the client is not an impostor and has a valid account. At this point, the SG will accept connection requests from that client. Once a connection is established through the Service Gateway it can count packets transferred, call setup requests or total connect time if usage-based billing is required.
- Protocol conversion between the ATM data stream and the format required by the service. This could include time slot assignment with a Class 5 telephone switch, or segmentation and re-assembly of IP packets to be forwarded to an IP router.
- Name assignment, where identifiers in the service name space are mapped into addresses in the Access Network. For example, an analog telephone line plugged into a telephony feature card in a Residential Gateway is mapped to a telephone number in the Public

Switched Telephone Network, so incoming calls to that number can be routed to the correct telephone.

- Maintenance and network management, as well as server support for client applications that execute in the Residential Gateway.

5. Advantages to Consumers

An Access Network incorporating Residential Gateways provides a number of benefits to consumers:

- A single access line can provide many services, so the addition of a new service does not require a maintenance call requiring new wiring to the house. For example, new telephone lines can be added without scheduling a service call from a telephone service provider.
- A consumer can have greater choice of service providers for individual services, and can change among them dynamically.
- Interactions between different in-home networks are possible because they all terminate at the Residential Gateway. For example, telephone call annunciation and caller-id could be indicated during TV viewing with on-screen graphics.
- Services that require "always on" functionality (like home security or utility meter access) are readily implemented, since the Access Network is always active and the gateway cannot be inadvertently turned off.
- Residential gateways preserve consumer investment in existing in-home networks.

6. Advantages to Service Providers

As the telecommunications market evolves from narrowband to broadband delivery, service providers also benefit from Residential Gateways in customers' premises:

- The access provider's risk is reduced, since it need not predetermine all the possible services to be provided on a new Access Network. Furthermore, broadband access provides the means of delivering new services that have not yet been developed.
- A change in the access infrastructure has little impact on customers, since the residential infrastructure does not change when a new access method is installed.
- The marginal cost of adding a new service is low, since there is no need to add new access infrastructure. An access provider that has traditionally been in the telephone business may prefer to delegate video services to outside vendors. These vendors need only a single trunk to connect to all the access provider's customers. The access provider benefits by being able to deliver a wider variety of services to its customers, and the other vendors benefit by getting easy access to a large customer base.
- Since Residential Gateways can have substantial processing power, service providers can decentralize their infrastructure. In telephony, for example, the POTS Feature Card is the equivalent of a line card in a Class 5 telephone switch, so central office switches need only trunk access and line growth is implemented at customer sites rather than in the central office.
- Because of the processing power available in the feature cards, service providers can "soft provision" new subscribers. For example, the first time a telephone is used, a connection is placed to an account establishment server rather than the voice server, and a new customer is added to the service provider's data base automatically. The number of telephone lines to the home can readily fluctuate with need.

7. Conclusions

Many different broadband access methods are emerging, delivering new services to homes and small offices. A small, modular ATM switch at the entry point of access into the home or office enables a wide variety of services to be delivered cost-effectively, while protecting both the consumers and the access providers from obsolescence. With attention to protocol details, the system is self-configuring, so that consumers need not read a manual in order to access new features. By providing a connection infrastructure, the Access Network enables service providers to implement their feature sets independently. The result is a wider variety of services available to consumers, a larger market for service providers, and an opportunity to create and deliver new services that are not presently feasible or perhaps even imaginable.