High Speed Internet Access Using Cable Modems with Telephone Return

Jonathan Fellows Ph.D., Victor T. Hou
General Instrument Corporation
Communications Division

Abstract

For many current cable service areas, telephone return cable modems may be a viable long term technology for delivery of high speed data services. The first generation of commercially deployed telephone return cable modems and associated headend equipment have now been installed in multiple cable plants. This system, incorporating 64-QAM transmission in the downstream and telephone return in the upstream, provides high speed access to the Internet and other data applications.

Many of the network design issues of telephone return cable modems, such as network addressing schemes, asymmetric bandwidth, and system management, will also apply to two-way systems. Other issues, such as integration with dial-up networks, and asymmetric routing, apply uniquely to one-way systems. Experience with performance tuning of TCP in asymmetric systems is described, as well as field experiences with installation and configuration of the modem in customer PCs.

TELEPHONE RETURN RATIONALE

This paper asserts that cable modems with telephone return paths are a practical option for delivery of data services in broadband cable plants, both in the near term and in the future. The remainder of the section motivates this assertion.

One of the dominant motivations for telephone return cable modems is that, in an era of capital scarcity, the cost of cable plant upgrades favors telephone return schemes. Due to the robust error correction capabilities of modern digital television modulation schemes, telephone return cable modems are capable of operating at high speed in practically any current cable plant.

Another motivation is that cable return path technology is not yet fully mature - no de facto standard has emerged in the marketplace. The engineering challenges of the cable uplink are not reduced to common practice. Finally, while there are proof of concept systems in use, there are currently no working prototypes of any of the proposed cable return standards.

Existing web-based Internet services have highly asymmetric bandwidth usage profiles, with much more data traffic directed toward the client than returning from the client. This traffic pattern is well suited to a cable forward, telephone return architecture. Telephone return cable modems support existing Internet services, such as the World Wide Web, at speeds that are at least two orders of magnitude higher than telephone-only Internet access.

The speed achievable using telephone return broadband distribution techniques is a major market discriminator - people will pay for existing services, only faster. The market does not need to wait for new "killer applications".

TECHNOLOGY OVERVIEW

Telephone return cable modem technology brings high bandwidth data connectivity to existing broadband cable networks. Host connections are established in the downstream direction through either internal or external cable modems. Host communications software can use either a telephone modem built into the cable modem or an existing telephone modem within the user PC to establish a dial-up session for return path data traffic. A set of telephone return cable modems that share access to a common broadband channel can be interfaced to a public or private internet through a headend cable router. Current generation downstream modulation techniques are capable of providing a 27 Mbps data subnet in a single 6 MHz TV channel, using 64 QAM modulation. Figure 1 shows the relationship between the above described components.

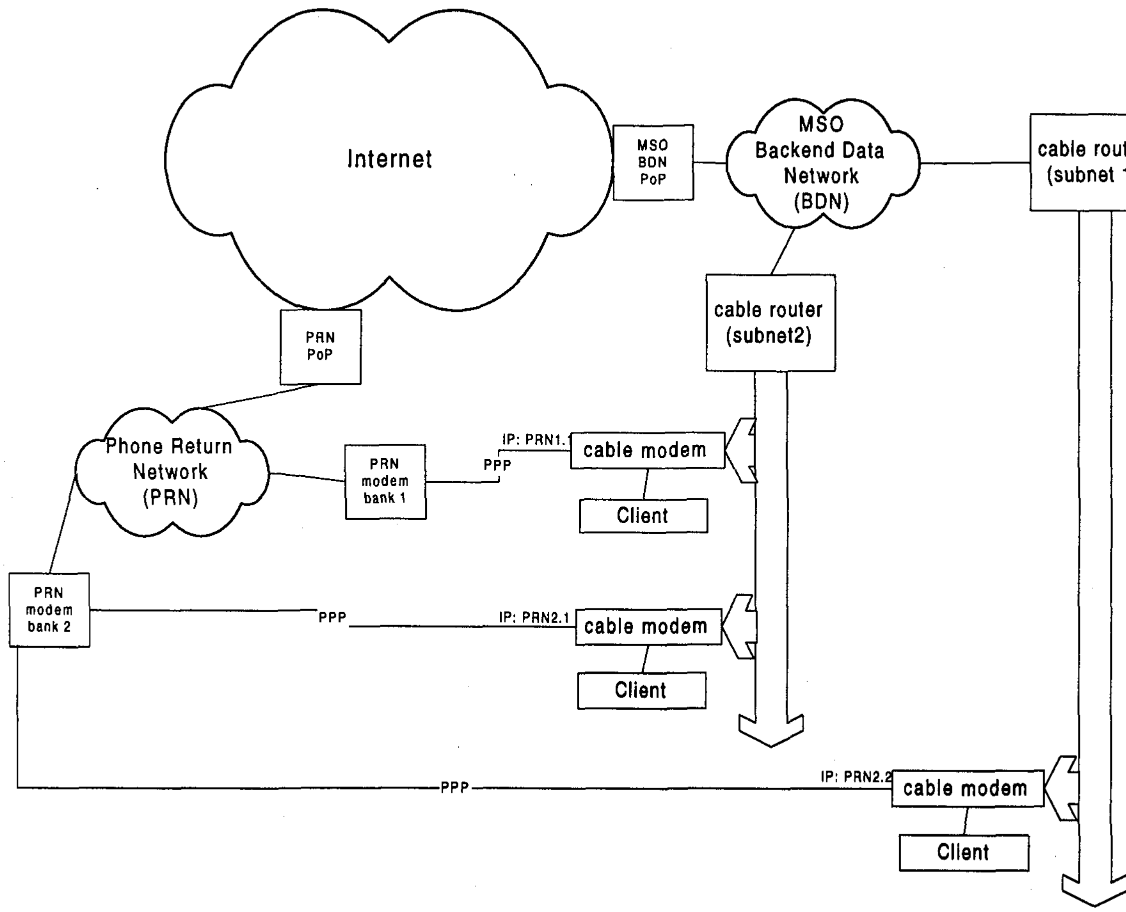

Figure 1 - Telephony Return Cable Modem Network Architecture

DESIGN ISSUES & APPROACHES

This section explores the basic design issues that have emerged for telephone return cable modems, and describes the choices made by General Instrument in its current commercial product line.

Internal vs. External modem

This choice, as it has evolved in current product offerings, involves more than a simple form factor. Current telephone modem products come in both external and internal form factors without changing the way in which they integrate with communications systems. The reason is that in both cases the telephone modem serves as a network interface device for a host that acts as an end system in a network. General Instrument has chosen this approach for its internal cable modem product. This choice offers the advantages of straightforward integration with existing Internet protocols, but requires the product to integrate with a wide range of PCs. This issue is revisited in a later section.

External telephone modems communicate with their attached host using serial I/O interfaces, which does not change the modem's status as a local network interface device. Many external cable modems have chosen to interface with their attached host using an IEEE 802.3 interface [1]. This choice forces the view that the host network interface is the 802.3 Network Interface Card. The cable modem becomes an intermediate system - either a bridge or a router. In either case, the cable modem is required to interoperate with a more complex set of protocols than is the case with an end system interface.

Broadband PHY and Data Link Framing

In late 1996, the North American cable industry agreed on major elements of interoperable digital cable systems. One of these agreements is the use of a downstream transmission standard that conforms to the International Telecommunications Union (ITU) standard ITU-T J.83 Annex B [2]. The specifications in Annex B include 64 QAM modulation, concatenation of a Reed-Solomon block code with an inner Trellis code, interleaving, and a contiguous serial bit-stream.

There are several sensible options for HFC data link framing and Media Access Control (MAC). The options with the best basis in existing commercial practices are Ethernet (IEEE 802.3), ATM, and MPEG-2. Of these, MPEG-2 is currently the best integrated with the ITU J.83B Physical Layer. Neither ATM nor Ethernet currently have widely accepted mappings to HFC Physical Layer protocols. The choice of MPEG-2 also leaves open the possibility of multiplexing data with video services. MPEG-2 is a particularly good choice for telephone return cable modems, since it was designed for one-way operation over HFC cable plants. As a practical matter, choosing MPEG-2 allowed development efforts to be focused on data networking issues.

Addressing and Data Path Selection

Mapping IP addresses onto data link addresses is a key issue in implementing IP over a new data link protocol. This mapping is needed to support IP forwarding in routers and hosts. For IEEE 802 MAC protocols, this mapping is provided by a broadcast-based Address Resolution Protocol (ARP). Use of an MPEG-2 based data link protocol requires a different approach to data link address resolution. This can be based on the association of an IP subnet with each MPEG Transport Stream used as a broadband data channel. The IP subnet is defined using variable length subnet masking, with a maximum subnet size of 4096 host addresses. (The remainder of the 13-bit PID address space is reserved for multicast and system management uses.) The hostid part of an IP address is then directly mapped to a MPEG Packet IDentifier (PID).

Routing vs. Bridging

This is not an issue for internal modems - an internal cable modem is a Network Interface Card (NIC) for an HFC subnet. An HFC NIC filters the HFC MPEG-2 Transport Stream for the PID that corresponds to its host IP address. It then forwards selected MPEG packets to its host for reassembly. A host with an internal cable modem always forwards outbound datagrams to its PPP connection.

It is possible to design an external cable modem as either a bridge (Layer 2 forwarding) or a router (Layer 3 forwarding). After extensive analysis and debate, the authors have come to the conclusion that either configuration can be made to work in two way cable plants, and that the two configurations are comparable in complexity. However, for one way cable plants and telephone return, IP routing provides significantly more flexibility for asymmetric data paths. We have therefore chosen a router based interface for our external cable modem.

The following forwarding conventions are proposed for an external telephone return cable modem acting as a router:

a. Outbound datagrams are forwarded to the cable modem PPP connection.
b. A cable modem filters its MPEG Transport Stream for the PIDs that correspond to any of its configured IP address. It reassembles IP datagrams and forwards them to the attached host.
c. A headend cable router always forwards inbound datagrams from its assigned subnet, using the PID derived from the IP address.
d. Routers in the Backend Data Network have a static route for the broadband subnet that points to the headend cable router.

IP Encapsulation

The choice of MPEG, with its 188 octet fixed size frames requires segmentation and reassembly of payload data from higher protocol levels, in order to achieve Protocol Data Unit (PDU) sizes that are efficient for data communication applications. Fortunately this has already been addressed in the MPEG community with the use of DSM-CC private sections. This entails the use of RFC 1483 encapsulation of payload datagrams[4], which includes the use of LLC/SNAP to denote the protocol type of the PDU being encapsulated These conventions provide for direct encapsulation of IP datagrams of up to 4K octets.

Quality of Service

There has been much discussion of multimedia applications and the Quality of Service support that such applications will require. Multimedia applications are rapidly being adapted to existing Internet delivery methods. Methods for real time delivery of digital sound, which can be compressed to fit today's telephone modems, have improved impressively in the last year. When cable modems provide the bandwidth needed for video applications, Internet delivery methods for video can be expected to improve in a similar fashion. An open question is whether these methods will build on experience with MPEG-2, which requires link level Quality of Service guarantees, or whether they will use methods that rely on more extensive use of buffering.

The currently proposed Internet approach for real time data services is based on the Real Time Protocol (RTP) and the Resource Reservation Protocol (RSVP). The HFC data link is not necessarily involved in either RTP or RSVP. Instead it can provide raw bandwidth which can be managed by the RTP/RSVP protocol implementations in hosts and routers.

Customer LANs

Local Area Networks (LANs) on the customer premises can be accommodated in two ways. When an internal cable modem is in use, the host can be configured as a dual homed host with interface to the cable network and to a local 802.3 network. All that is required is to obtain IP addresses for the LAN (this is easier if addresses are assigned statically) and enable IP forwarding in the dual-homed host. This works today on hosts running the Microsoft NT operating system, and can be made to work with Microsoft Windows 95 with third party software. It is also possible to configure the home LAN so that local hosts have private IP addresses.

When the cable modem is external, support for a home LAN is straightforward. The cable modem acts as a bridge and/or router and supports multiple locally attached hosts. The same addressing choices are available as were described above.

Integration with Dial-up Networks

One of the advantages of an IP-centric network design is that IP networks "just work" under an amazingly wide set of circumstances. Separate routes for incoming and outgoing traffic poses no problems to a standard IP network. This means that integrating a cable modem with a telephone return is simply a matter of setting default IP forwarding addresses appropriately.

System Management

The major system management issues for telephone return cable modems are IP address management, SNMP monitoring, and diagnostic support.

IP Address Management A host with an internal cable modem always has two media interfaces, one telephone, the other broadband. It is possible to configure the host with either one or two IP addresses. A host attached to an external cable modem needs only a single 802.3 media interface and a single IP address.

In the case where the host with an internal modem has one IP address, it is necessary to coordinate IP address assignment in the Telephone Return Network with the broadband data channel being used. This can be accomplished either through static address assignment conventions, or by adding IP address management functions to the dial-in network authentication servers.

In the case where the host with an internal modem has two IP addresses, there is no coordination required between telephone address assignment and broadband address assignment. This is very convenient when the dial-up telephone network is outsourced to an existing Internet Service Provider.

An external modem can be configured with an unnumbered interface on its telephone interface, or it can be configured with a routable IP address. The broadband interface of an external modem can be configured as an unnumbered interface or it can be configured with a routable IP address. So the external modem has two media interfaces and zero to two IP addresses depending on how it is configured

SNMP A telephone return headend cable router should support an SNMP MIB that includes MIB - II. Proprietary extensions are capable of supporting data collection on a destination address basis for usage based billing. MIBs and agents for both cable modems are under development. These MIBs will support HFC transmission parameters and cable modem diagnostics.

EXPERIENCE

Performance

In data communications, two of the most important performance metrics are delay and throughput. For the primary applications of Web surfing and file downloading, the important aspect of throughput is downstream throughput.

One of the characteristics of both two-way cable modem systems and cable modems with telephone return is bandwidth asymmetry. The data rate in one direction is substantially greater than the data rate in the opposite direction. The 64 QAM downstream is capable of an effective data rate of 27 Mbps. With a telephone return modem of, for example, 28.8 kbps, there is a high degree of asymmetry.

Testing shows that telephony return cable modem throughputs for ftp downloads can achieve 3.7 Mbps using a 133 MHz Pentium PC running Windows 95. With simultaneous TCP connections to multiple PCs, an aggregate downstream throughput of approximately 24 Mbps has been achieved. This is nearly 100% link utilization, after accounting for MPEG framing overhead and segmentation quantization effects. It should be emphasized that these are data rates as seen at the application level and not at a lower layer where additional overhead has been added.

Now, we examine downstream latency. It is noted that transmission from the headend is approximately 445 μs for a 1500 byte packet based on a data rate of 26.97 Mbps. The headend cable router buffers downstream traffic, so there is a random waiting time. The propagation delay is proportional to distance and is roughly 375 μs for a reasonable maximum distance of 50 miles from the headend. The delay due to the downstream FEC (Forward Error Correction) interleaving is approximately 4 ms. This is a constant delay. So the downstream latency for a 1500-byte packet to be transmitted by the headend and received at the receive end has a minimum of about 5 ms, dominated by the interleaving delay.

Upstream latencies depend on the distance, the telephone modem rate, the fixed latencies in the modems, and the latencies of the terminal server and routers in the headend network. Of course, there are additional latencies for negotiating through the Internet to the communicating server or much smaller additional latencies for communicating with a local content server in the headend network.

Network Integration

Our design philosophy has been heavily Internet-centric, and this has paid off with a nearly flawless record of smooth integration of the headend cable router into existing IP networks. All that is required is the installation of a static route from an existing router that points to the headend cable router for the HFC subnet.

Client Installation & Configuration:

Installation of an internal cable modem into PCs imposes no particular requirements other than those that would normally be associated with installation of any Network card into a PC. With a "Plug & Play" compliant device, systems running Windows95 will automatically detect the presence of the cable modem on boot up. When installing on a Windows 3.1.X system installation requires the use of an external Plug and Play utility, such as Intel's ICU. Installation in most cases is straightforward for either platform provided that precautions are taken in advance to insure the presence of free IRQs and I/O address space for use with the cable modem. Some "off the shelf" PCs have a default configuration where all IRQs are already assigned leaving none available for the cable modem. For these systems it is necessary to remove a device to free up an IRQ. The most common device selected for removal is MPU 401 (MIDI emulation).

CONCLUSION

The basic point of this paper has been that cable modems with telephony return constitute a technology that meets the needs of today's Internet applications, in a way that is fieldable on today's broadband cable plants. This represents an opportunity for immediate deployment of Internet services that offer end users throughput that is at least two orders of magnitude higher than current generation technologies.

REFERENCES

[1] ISO/IEC 8802 3: 1996 (ANSI/IEEE Std 802.3, 1996 Edition), Information technology - Local and metropolitan area networks - Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications.

[2] ITU-T Recommendation J.83, 10/95, Annex B, Digital Multi-Programme Systems for Television, Sound, and Data Services for Cable Distribution. Note that [SCTE DVS-031] Mode 1 for 64 QAM is essentially identical.

[3] ISO/IEC International Standard 13818-1, Generic Coding of Moving Pictures and Associated Audio: Systems, 13 November, 1994.

[4] Heinanen, J., Multiprotocol Encapsulation over ATM Adaptation Layer 5, IETF RFC 1483, July 1993.