Internet Protocol (IP) vs Radio Frequency (RF) Television Distribution

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Revised 20 February 2006

Summary

The advent of high-speed residential Internet access creates an alternative delivery method for video programming. Where adequate bandwidth exists IPTV is capable of a much richer suite of services then either CATV or over-the-air distribution. IPTV uses digital packet technology to converge TV/Radio with data eliminating need to build a separate application specific network for each. IPTV is capable of delivering traditional "broadcast" one-to-many programming that exists today. It is also well positioned to support video on demand services. Over time online libraries will allow patrons to check out video or audio productions and view them immediately.

This paper examines technical considerations of conventional RF TV and IP based digital distribution. Key advantages of IPTV are noted and technical challenges to IPTV deployment discussed.

Short History of Cable TV

In the early days of TV shortly after WWII many communities experienced poor TV reception, either due to remoteness or terrain. Entrepreneurs discovered installing a large antenna in a preferred location and delivering broadcast TV programs over coaxial cable solved the problem. This was the humble beginning CATV industry, CATV originally meant Community Antenna Television.

Over time the role of CATV expanded. Because CATV signals are confined within the distribution network it is possible to reuse frequencies allocated to over the air radio services increasing number of channels. This allows CATV to provide many more channels then over the air broadcast. Broadcast TV occupies two bands Channels 2-13 are VHF, 14-69 UHF; the FCC has recently reallocated the upper UHF TV channels reducing the number of over the air channels. CATV systems typically provide about 130 channels, double that available over the air.

As CATV became more popular entertainment networks that have no over the air counterpart were created taking advantage of the large channel capacity and low cost of cable distribution.

Most recently the Cable TV industry enhanced one-way video distribution network to two-way allowing it to deliver high speed Internet service.

Cable TV Technical Issues

The CATV industry is based on analog broadcast TV standards; in the US each TV channel occupies 6 MHz. Analog TV specifications were developed prior to WWII as the result of extensive experiments in human perception. Modern digital techniques allow much greater channel carrying capacity. Digital encoding allows each channel to carry approximately 40 Mbps. This can use used for Internet access as done by the DOCSIS cable modem standard or to deliver multiple High Definition TV (HDTV) or Standard Definition TV (SDTV) program streams. Each compressed HDTV channel requires about 19 Mbps allowing a single 6 MHz channel to deliver 2 HDTV streams. SDTV requires about 3 Mbps allowing a single channel to carry up to 12 TV programs.

In order to compare traditional CATV to an IP digital network we need to determine its data carrying capacity. A 1 GHz CATV system of 158 channels of 40 Mbps each results in total system capacity is about 6.3 Gbps. This is a large number but well within the capacity of a single Ethernet interface.

The CATV distribution network “broadcasts” the same programs to all customers. The is a cost effective technique for real time TV distribution but has severe limitation when used with pay per view and demand based service. A state of the art 1 GHz fully digital CATV system is limited to about 300 HDTV or 1800 SDTV programs. However going full digital requires a set top box at each TV. Most Cable systems are limited to about 850 MHz and offer a mix of analog and digital channels reducing practical systems to about 50 digital channels able to support 100 HDTV or 600 SDTV programs in addition to analog channels. This is an impressive number if the system remains a real time broadcast network. However the enthusiastic acceptance of Personal Video Recorders (PVR) indicates there is tremendous demand to view programs at a time chosen by the customer rather then when originally “broadcast.” This is the Achilles heel of the CATV network. It has limited capacity to deliver demand based programming. This can be offset to some degree by using customer PVR to prerecord programs for later viewing. Limited CATV bandwidth is one of the reasons Cable industry has been so reluctant to comply with FCC must carry rules for HDTV.

To put this problem in perspective lets assume a MSO service a small town of 5,000 residences, population 20,000. Assuming a family of four each watching a different demand-based program requires network to deliver 20,000 separate video streams. If these are all HTDV network must be capable of about 400 Gbps. This is over 60 times the capacity of even the most sophisticated CATV network. Even if demand based service is limited to SDTV bandwidth is still 10 times the capacity of the CATV network.

CATV RF channelization scheme has many of the same ramifications as circuit switching used by the telephone industry for voice calls. Capacity is divided into channels allowing efficient use of both bandwidth and transmission hardware. Unfortunately, as technology changes new functionality must be shoehorned into the existing channel allocation.

Leveraging the installed based reduces incremental cost but is less cost effective then moving to new technology optimized for the new services over the long run.

The CATV network is a “broadcast” networks much the same as over the air transmission. Programming originates at the CATV head end and all programs are simultaneously delivered to all customers. This results in a very simple transport network but requires a complex security scheme to limit access to optional programming. The Set top boxes used by the CATV industry face a never-ending war with pirates. As each security measure is hacked a new one must be developed to take its place.

RF channelization means reception of each channel requires an RF front end and a MPEG decompression engine to recover compressed digital information. In the case where multiple video streams are multiplexed within a single channel the box must demultiplex the streams before decompressing the desired stream. In order to view multiple video programs the set top box must incorporate multiple RF front ends and decompression functions.

Given the changes in viewing habits and advances in technology over the last 60 years one must ask if extensions to the tradition CATV network make sense or is it time to look at an entirely new means of distributing TV and movies.

IP TV Technical Issues

The rapid growth of the Internet over the last ten years has transformed society and changed the way people think about electronic devices. Never before have ordinary citizens been able to instantaneously communicate with anyone in the world almost for free. Never before has it been so easy to publish. Publishing on the Internet is as simple as setting up a web server, thus making the author’s work available to anyone with Internet access.

This begs the question. Can the Internet be used to deliver video programming at lower cost then existing technology? This is already being done to a limited extent; Internet radio stations exist and it is possible to view low-resolution poor quality video over the Internet now.

IPTV is a robust platform aimed towards the future. It eliminates bottlenecks inherent in the present CATV network creating and provides low cost path to future enhancement. New service offering can be implemented by changes to the head end, similar to the way the Internet works today. This largely decouples the access network and customer equipment from service offerings allowing new services to be delivered more rapidly and at lower cost then traditional means.

This section examines the technical requirements to deliver high quality video over IP. In keeping with the egalitarian nature of the Internet we will start from the customer perspective and work our way to the producer – rather then the more traditional way round. In talking about IP and the Internet we are discussing using IP protocols in the metropolitan access network to deliver high quality television programs. Extending this capability to the Internet at large is possible but beyond the scope of this paper.

Customer Access

As stated previously each HDTV stream requires about 19 Mbps, packaging this stream for IP transmission requires some overhead so we will round up to 20 Mbps. Assuming a typical family of four the residential link must be capable of delivering at least 80 Mbps. Fast Ethernet (100 Mbps) is available over both fiber optic and UTP copper cable. Gig Ethernet (1,000 Mbps) is also widely available. While ten times faster it is only slightly more expensive then Fast Ethernet. Clearly transporting IPTV data within the home is not a significant problem.

Current Cable and DSL broadband services run the gamut from about half megabit per second to 10-30 Mbps. At best Existing Broadband is only capable of delivering only a few SDTV programs. Fiber to the Premise (FTTP) metro network is required to deliver the type of bandwidth needed for full-blown IPTV service.

Customer Premise Equipment

IPTV requires a set-top box at each TV. The most popular interface is Ethernet, rather then coax used for CATV. The physical interface is not limited to Ethernet; any medium capable of delivery IP data rapidly enough can be used, such as IEEE 1394 Firewire or IEEE 803.11 WiFi radio. This is a less costly interface then the RF front end required by CATV. Unfortunately, at least in the short term, lower production volumes of IPTV boxes vs conventional CATV set top boxes means they tend to be more expensive the mainstream counterpart. Customer premise distribution network is not limited to TV delivery. All communication services can be delivered over a single converged IP distribution network. Over the long term this eliminates need to wire residences with three different cabling systems, one for Data, another for TV, another for Telephone. See Future of Home Networking for more musing on this topic.

Intelligent devices such as PCs do not require a set top box at all. Any network device equipped with the proper software is able to receive TV and radio programs.

Each Ethernet device is connected to an Ethernet switch; the switch is connected to customer's broadband router and the router in turn to the metro network termination device (DSL, Cable, FTTP etc).

Customer premise network should support Quality of Service (IEEE 802.1Q) to give priority to latency sensitive traffic. It also should support Internet Group Management Protocol (IGMP) to intelligently forward multicast packets rather then flood them to all destinations.

Access Network

Fiber optic cable is the ideal medium for delivering high-speed access: it is cheap, has tremendous bandwidth and immune to electromagnetic interference. It is possible to build a fiber optic network and directly connect each subscriber to the head end. This in fact is how most of the 100-year-old copper telephone network operates. The down side of this technique is the tremendous number of cables that converge on the head end. A more cost effective approach is to implement a tiered system that reduces the amount of wiring. In an optical network this can be done using Passive Optical Networking (PON) or Switched Ethernet.

PON

A Passive Optical Network (PON) network operates much like the traditional CATV network. A head end "broadcasts" to all customers. Intelligence in the User Network Interface (UNI) ignores data for other customers, accepting only data intended for the particular customer. Transmission toward the head end is more complex since many customers share the circuit. A Time Division Multiplexing (TDM) scheme is used where the head end determines when each customer is allowed to transmit.

A-PON was developed by the ITU. It uses Asynchronous Transfer Mode (ATM) for low level data delivery. A-PON delivers 622 Mbps toward the customer and 155 Mbps up. ATM adds 10 % overhead so a 622 Mbps connection only delvers 563/140 Mbps. Assuming each customer requires 80 Mbps just for video an ATM-PON system is limited to no more then 7 subscribers. Less if Internet access is also desired. If service is restricted to SDTV up to 50 subscribers per PON are possible.

The IEEE 803.3 Ethernet in the First Mile task force created an Ethernet version of PON, called Ethernet PON. E-PON operates at 1 Gbps and does not use ATM eliminating the so-called ATM cell tax.

The latest ITU PON version is GPON operating at 2.4 Gbps toward customer and 1.2 Gbps upload. It also does away with ATM reducing low-level overhead. Assuming a standard 1:32 split ratio G-PON delivers 75 Mbps per customer.

The advantage of PON is elimination of active electronics in the access network. PON works best when customer requirements are bursty, such as web browsing. IPTV requires a constant stream over long periods of time. Delivering high quality TV is very bandwidth intensive negating much of the advantage of PON.

Switched Ethernet

An alternative to PON is to locate active electronics in the access network relatively close to the customer. This creates a more flexible architecture supporting a wide mix of residential and business customers. Switched Ethernet uses edge switches to aggregate multiple customers onto high-speed trunks. The trunk carries packets to the head end. This arrangement supports an unlimited number of customers – limited only by the size of the switch and trunk capacity to the head end. In a switched Ethernet network the customer interface only carries data destined for that customer allowing it to operate at a relatively low speed and improving security compared to PON.

Remote electronics are more fragile then passive equipment and requires a reliable power source. This necessitates housing equipment in a climate controlled communication hut. Mains power will typically have to be backed up with local generation to protect against power outages.

Remote switching centers can be any size. Large switches reduce per customer cost of common equipment, while increasing cost of outside plant since average cable run is longer.

Head End

While bandwidth in a Fiber to the Premise (FTTP) network is cheap transit bandwidth from the head end to remote locations is still expensive. This requires the MSO be located in close proximity to the head end. Broadcast feeds are obtained from geosynchrous satellites. Direct connection or over the air antennas are used for local stations. As real time material is received it is stored and cataloged making it available in non real time whenever customers want to look at it.

IP distribution differs from traditional CATV practices. Real time IP streams are multicast rather than broadcast. This means customer equipment has to tell the head end which programs it is listening to. Switches between the head end and end user are programmed to forward only selected programs to the customer. This makes efficient use of network bandwidth since only a single copy of the program needs to be propagated throughout the network. Pruning the path prevent programs from overloading links where no one is interested in the material. IPTV dramatically improves content protection. Since only material selected by the customer is delivered to the customer theft of service problems are largely eliminated.

Multicast uses Internet Group Management Protocol (IGMP). Think of the access network as an inverted tree. The head end is the trunk; Ethernet switches are the branch intersections, customers the leaves. Each switch examines the packet to decide which port to forward it to. If no one downstream of the port is listening the packet is not forwarded to that port. This limits packet flow to only those links necessary to connect to customer signed up to receive the material. IGMP allows efficient use of network resource.

Demand based programming is delivered on a point-to-point unicast basis the same as most other Internet access. In that case the network must have enough capacity to support thousands of individual program streams.

Media Server Farm

Demand based video is very bandwidth intensive. Each program stream must be served separately. This poses significant scaling problems. Server loading is a function of video quality and number of video streams. Demand based TV require massive server farm to both catalog recorded program material and deliver it to multiple customers.

Challenges implementing IPTV

Any new technology faces challenges as it matures. IPTV is no different. Implementations face both business and technology issues. This section discusses issues that need be addressed when implementing IPTV service.

Multi Service Operator (MSO) Content Aggregator

IPTV is still relatively rare – only a few players offer service over high-speed networks. These companies must be evaluated carefully to insure they are financially stable and have the business and financial depth to offer advanced services to take advantage of the unique characteristics of the IP access network.

Demand based content service requires large high capacity server farms. At 19 Mbps a 90-minute HDTV movie requires about 13 Gig Bytes of storage. Multiple this by thousands of titles and thousands of customers the requirement are staggering.

Copyright

Content owners represented by the MPAA and RIAA are struggling to come to terms with Internet content distribution. On one had digital distribution dramatically reduces cost of connecting artist to patron. On the other it undermine the traditional retail distribution chain and allows individuals to share recorded works among themselves easily.

IPTV is yet another move along this continuum and represents difficult business transition for traditional players.

Access Network Bandwidth

Delivering video over IP is bandwidth intensive. Video streams not only require very high-speed connection they persist for a long period of time. Common oversubscription ratios acceptable for Internet access are inappropriate when video becomes a large portion of overall traffic.

Access networks optimized for video distribution should include a traffic prioritization scheme (IEEE 802.1Q) this enables low bandwidth latency sensitive traffic, such as voice, top priority. Video falls in the middle it is not as latency sensitive as voice but excessive delay causes frames to be dropped and audible anomalies. The network should support multicast in addition to unicast. This allows a single copy of the program to be sent to many customers conserving network bandwidth.

The popularity of IPTV will increase over time. This requires careful tradeoff of current vs future capacity. Installing too much capacity wastes scarce capital. On the other hand installing equipment that needs to be replaced in a few years is also wasteful. One needs to strike a balance.

Customer Equipment

IPTV requires an Ethernet set top box at each television. In an IPTV environment the TV acts as a dumb monitor. Computers do not require special hardware as long as they are running IPTV software. This is one of the advantages of IPTV; any device connected to the LAN is able to receive programs.

Most homes are not wired for Fast Ethernet. Deployment of IPTV means either the homeowner or IPTV supplier be capable of installing not only the set top box but also Ethernet cabling and equipment. As WiFi performance improves the need for hardwired connection will be reduced. Over the air link can be used to connect devices to home network. If an Ethernet LAN already exists the installer must insure it is capable of meeting the heavy demand of IPTV.

In most cases Fiber to the Premise (FTTP) customer interface terminates at a broadband router. A router allows a single IP address to be shared by multiple devices on the LAN. IPTV is a very demanding service. Not all broadband routers have 100 Mbps WAN ports or enough internal processing power for IPTV. The IPTV vendor should maintain a list of compatible equipment to help customers avoid disappointment.

There are several startups offering equipment to allow in home TV coax cable be used for Ethernet. This may be a good solution in some cases but most likely the best solution is to run new Ethernet cable.

Sharing IP addresses requires some degree of synchronization between the ISP and IPTV provider. Most residential Internet accounts use dynamic IP addresses – this prevents the IP address from being used as a stable identifier by the IPTV service. It also means the address may change unpredictably interrupting programming. Another approach is for the IPTV vendor to issue their own address to subscribers. Since address scope is limited to the IPTV network the vendor need not use public addresses, private addresses are fine. This requires a router that accepts multiple IP addresses on its WAN port and the ability to determine which IP address to use for outgoing traffic.

Customer devices should monitor QoS tags (IEEE 802.1Q) giving priority to latency sensitive traffic.