Application Note

Building the Next Generation Multi-Service Broadband Network

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Part Number: 350077-001

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Executive Summary

There is a current industry rush to provide "multi-play" offerings to broadband subscribers. New network architectures are being developed and deployed to provide voice, video, and data services to customers over a single physical connection into the home. Although there is typically an emphasis on video delivery due to its high bandwidth consumption and its required inclusion in a foundation broadband offering, the full portfolio of broadband-enabled services should not be overlooked. The wide variety of consumer electronics devices and the services they support will have a major impact on the design of the home network and thus how services should be delivered to the user.

The heart of a broadband offering from a revenue perspective will trend to "on-demand" unicast services such as Video on Demand (VoD), voice, messaging/collaboration, gaming, and audio streaming where each end user has unique application flows and usage patterns that cannot be properly serviced by broadcast-oriented content. These unicast services will provide for Service Provider differentiation along with opportunities for incremental revenue in the broadband portfolio as the basic broadcast video, voice, and Internet elements become commodity items.

These applications will drive an ever-increasing appetite for bandwidth and the access technologies must continue to scale to provide higher levels of capacity out into the home at a lower cost per bit. Newer generations of access technologies deployed for higher speeds or cost reduction should be decoupled from IP service control to remove any dependency on the access product deployed and the services it can delivery. The IP service control elements must remain access agnostic to enable continuity of the services portfolio while the access technologies continue to evolve.

Whether considering HFC, FTTP, xDSL, or wireless access networks, the same requirement for a central point of per-user service and policy control of unicast application sessions will be necessary to offer a proper level of experience to each subscriber. This includes bandwidth control to facilitate service level guarantees, security, Lawful Intercept, billing, and access controls to content. The network must be implemented to not only provide a cost effective solution to the current generation of broadband services, but must also have a rapid service creation capability to extend to these more feature rich streaming unicast applications that users are beginning to demand.

The Race to Win the "Multi-Play"

The residential market has changed from the initial "single play" offerings of voice services from the phone company and TV services from network and cable providers. The Internet led to phone, cable, and satellite providers providing broadband delivery to the home and the first true competition as each tried to receive incremental revenues with "double play" portfolios. With each providing two of the three key services available in the residential market, there is now a competitive push to offer all three major services: voice, video, and Internet to further extend revenue opportunities and reduce customer churn.

The traditional "triple play" offering is already provided by many Service Providers. The convergence however is typically done by marketing relationships when combining Direct Broadcast Satellite (DBS) operators with DSL providers or through logical partitioning of the access network as seen with the cable operators. This effect begins to commoditize many of the standard triple play features. Voice is being cannibalized by the wireless providers, CLEC's, and Internet voice companies while broadcast video content is becoming a commodity feature with the only differentiation being the method of delivery to the home. The Internet has morphed into a "big pipe" with users purchasing a "speed", but typically only best-effort IP services from their broadband company.

Early differentiation beyond triple play has been observed with the addition of wireless services to provide a single bill for the consumer. Triple play is rapidly evolving to become more than a billing relationship with a customer. Service Providers will need to leverage their network-based capabilities to differentiate their broadband offerings. This has pushed providers to look beyond the three essential services to move to a "multi-play" solution that encompasses not only security and wireless-wireline integration as part of the service bundle, but also newer types of multimedia content. The multi-play solution will continue to evolve as competition necessitates the requirement for continued service differentiation.

This race for the multi-play leads to a few simple observations:

- Instead of a "single-service" provider where the consumer looks to separate companies for their voice, video, and data they will now look to a "single" Service Provider to offer the whole portfolio to meet their broadband needs. Once monopolistic entities such as MSO's and RBOC's are now competing for sole ownership of the consumer's monthly bill. Note that 69% of respondents in a 2004 Parks Associates survey of Internet households indicated a high likelihood of switching to a single company offering TV, Internet, and telephone services on one bill.
- The commodity effect of basic triple play services (voice, video, and Internet) will quickly lead to pressures for service differentiation and price competition/cannibalization. This new generation of Broadband Service Providers must look for new types of communication, productivity, utility, and entertainment services to provide additional value to their customers. Price competition alone will not suffice to capture additional market share.
- The consumer acceptance of broadband Internet has rapidly changed the consumer electronics market so that it is now impacting broadband network requirements. Once a silo effect of traditional electronics vendors, this market is also converging as more products not only adopt, but rely on IP and shortly thereafter, the home and public IP networks. The growth in home networking is now leading to a growth of in-home connected devices and in-home content sources. Media center PC's, online gaming consoles, network-connected stereos, and portable media devices have led to an insatiable desire for real-time multimedia content – both in the home and beyond. IP content and premium connectivity will drive the next generation of broadband traffic.
- The full acceptance of IP as the de facto networking protocol will lead to a fully IP connected home with all services, including triple play, as a single set of offerings over a common network infrastructure.

All of these observations lead to the single conclusion of a ubiquitous IP home network and pent up demand for new services that extend beyond the typical triple play. Service differentiation will not be met by offering broadcast TV alone, but instead of through the delivery of new types of content to the home on a per-user "on-demand" basis along with service guarantees that meet user expectations.

Instead of using the basic triple play silos, Service Providers must evolve their service portfolio and morph into the new types of multi-play categories shown in Figure 1 including communications, entertainment, education, utility, and productivity as dictated by the capabilities of the consumer electronics devices now entering the home. This pushes away from a basic best-effort delivery model to a broadband network that can differentiate application flows and provide the proper level of quality of service, policy control, and security without any impact to forwarding performance.

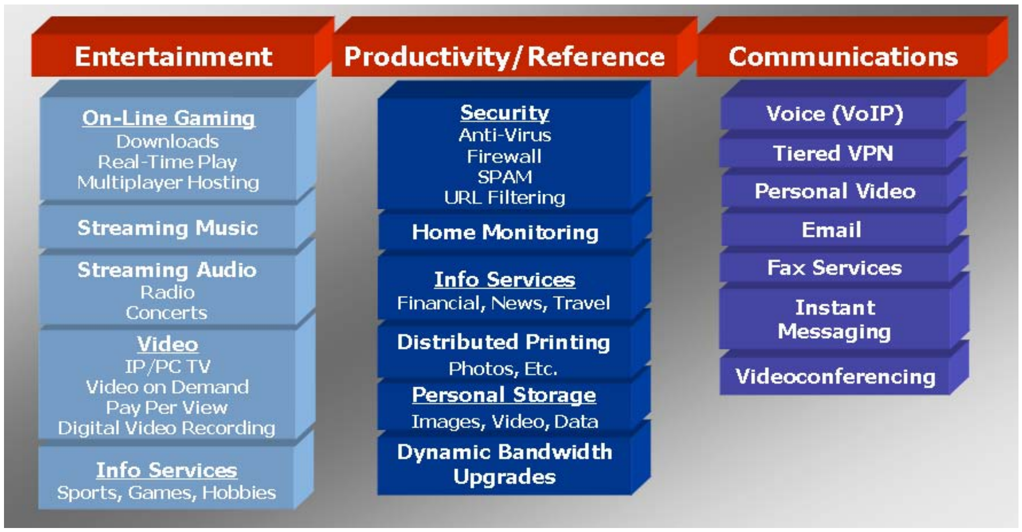


Figure 1: A new vantage point for looking at broadband service silos.

This type of service model also begins to minimize the differentiation of business and residential broadband customers. Many of the same basic network requirements for applications will be common between the two sets of customers. A telecommuter working from a home office will not be very different from a small office requiring voice, data, VPN, and collaboration services. The network should be able to handle any type of application flow for any customer, business or residential, based on bandwidth, loss, and latency requirements while ensuring effective security and service levels between user classes.

The Evolving Digital World: Looking Beyond Today's Triple Play

Although the Internet has been given most of the credit for the proliferation of IP-based services, recognition should first be given to the creation of digital technologies. This move from analog to digital media has been seen over the past several decades with the introduction of CD and DVD players, digital cameras and camcorders, TDM voice switches, portable MP3 music players, wireless networks and a multitude of other technology areas impacted by the encoding of information into 1's and 0's. Although the initial catalyst for digital technologies was the quality of reproduction and playback [compare a VHS output to a DVD], IP networks brought a new use: the digitization of content allows for new ways to transfer information by passing the 1's and 0's around the network within IP packets instead of using physical media such as disk or tape.

Content digitization and packet networks have resulted in an over-abundance of both client-server and peer-to-peer applications. The Internet is the original mass-market transfer network for these application including file-sharing, messaging, multimedia streaming, music downloads, VoIP, conferencing, among a long list of entertainment, productivity, and communication utilities. A sample of these types of applications is shown in Figure 2 along with their network impacts in terms of bandwidth and loss/latency sensitivity.

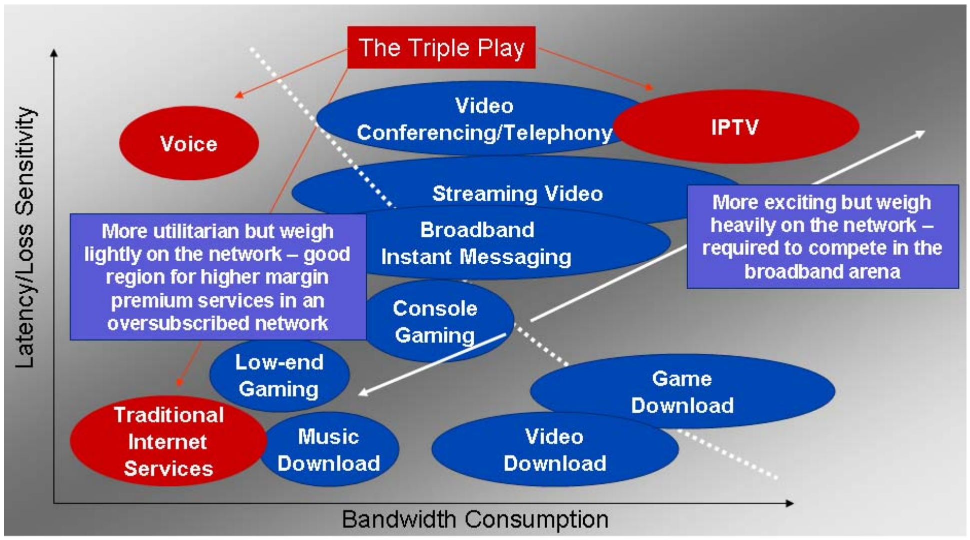
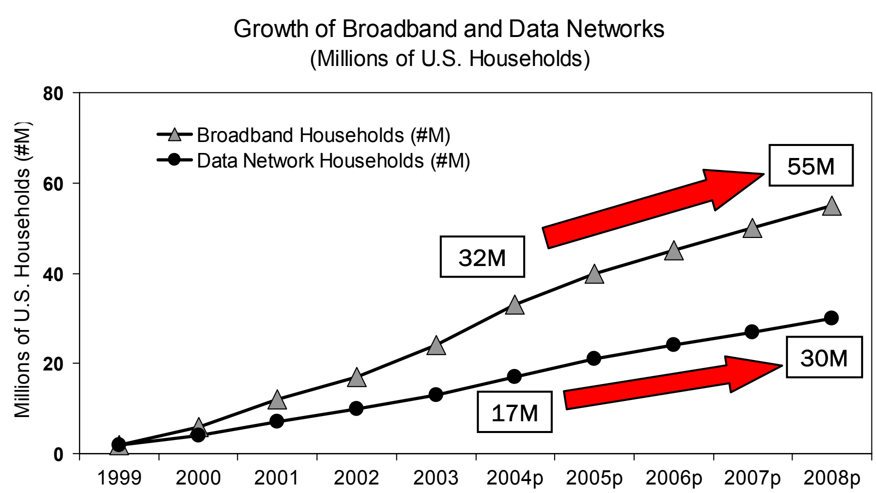


Figure 2: Varying applications and network impact

The original Internet generation found these capabilities limited to the PC, the only device typically connected to a dial or broadband connection. Now the consumer electronics market has jumped in on two fronts: (1) network devices to create a home network, and (2) host devices that can take advantage of the home network.

Home networks constructed over power circuits, Cat5 cabling, coax cabling, or using wireless access points are rapidly penetrating the residential market. Growth estimates show penetration in excess of 25% of US households, with over 50% of broadband customers having a home network as shown in Figure 3. Continued efforts to simplify the residential network are underway to ease the installation process and make it more consumer friendly instead of adopting enterprise technologies for the home. The standards 802.11n, MoCA, HPNAv3, and HomePlug are examples of this transition.



US Households with Data Networks		
	2003	2008
Ethernet	8.5M	13.4M
Wireless	3.3M	12.4M
Powerline	500,000	2.8M
Phoneline	700,000	800,000
Other	100,000	600,000
TOTAL	13.2M	30.1M

Figure 3: Growth of broadband and home network along with home network implementation technologies. Source: Parks Associates

Once the home network is in place the second phase of the consumer electronics market can now take shape. Media center PC's, streaming audio/video systems, online gaming consoles, and portable media viewers are just the early entrants into the market to allow for the sharing of digital content within the home and ultimately across a broadband connection.

The consumer electronics adoption of online IP devices and home networks will continue to evolve the consumer beyond basic PC awareness to point-and-click interfaces on more simplistic devices such as a streaming media player or video phones. Many of the configuration tasks will move to more friendly graphic interfaces mirroring a common web session or DVD menu selection and ultimately to automatic configuration with direct communication between in-home devices with the evolution of standards such as Universal Plug-n-Play (UPnP). The addition of end devices to the home network will be no more complex than plugging a phone to a jack or the TV to a video outlet as done today in the home.

As the network becomes easier to use, the same paradigm of the "empowered user" that has driven Internet usage and more recently the growth in a la carte music stores, time shifted television, and movies on demand will enter all aspects of the consumer lifestyle. Broadcast technologies will become limited to mass market or live delivery of content while the broader array of applications will trend to unicast. This includes video on demand, IP communications such as VoIP and messaging, music on demand, meetings on demand, gaming on demand, shopping on demand, and many other "on demands" that allow the connected consumer to react to impulse decisions now made possible in a digital online world.

As the unicast broadband market grows, the demands on the network will increase on two fronts. The first is that consumers will exhaust any available resource provided to them as the market adapts to higher capacity rates. This is a common technology trend seen with memory, CPU, and bandwidth offerings. This is being seen today as many VoD providers are upgrading content from 700kbps to 1.5Mbps to adopt to the faster subscriber access speeds. Whether movie downloads or streaming, this will have a major impact regarding network capacity requirements. The larger file sizes and multimedia streaming will have long-lived flows at potentially higher throughput rates than legacy Internet applications. The second is the number of devices accessing content from within the home. Instead of a single PC, the growth in home networks leads to more devices within the home accessing content. Multi-PC homes and digital streaming appliances will multiply the amount of average traffic sent and received per household.

As the digital media market moves forward, the average consumer will continue to not only exhaust network resources but will also begin building a large storage network within the home consisting of photographs, videos, movies, and music. This leads to an opportunity to offer storage and backup services beyond the home similar to online photo stores today. This along with peer-to-peer networking, remote access to home servers, and bi-directional offerings will begin to strain the upstream capacity of the network. This leads to the home network requirement for control of application flows from the home to the network through a single upstream IP control point: the routing gateway (RG).

The ultimate goal of the home network is to allow a device to retrieve or send data within the home or over a broadband connection. The device may support a single service such as voice or may extend across service boundaries as seen by PC's and gaming consoles. The easiest way to meet this goal is to build a common home network utilizing a single, shared session to the broadband provider. This connection should be terminated into a routing gateway that provides network, content, and application-level security along with QoS functions for the home network. An example of this type of network is shown in Figure 4 below.

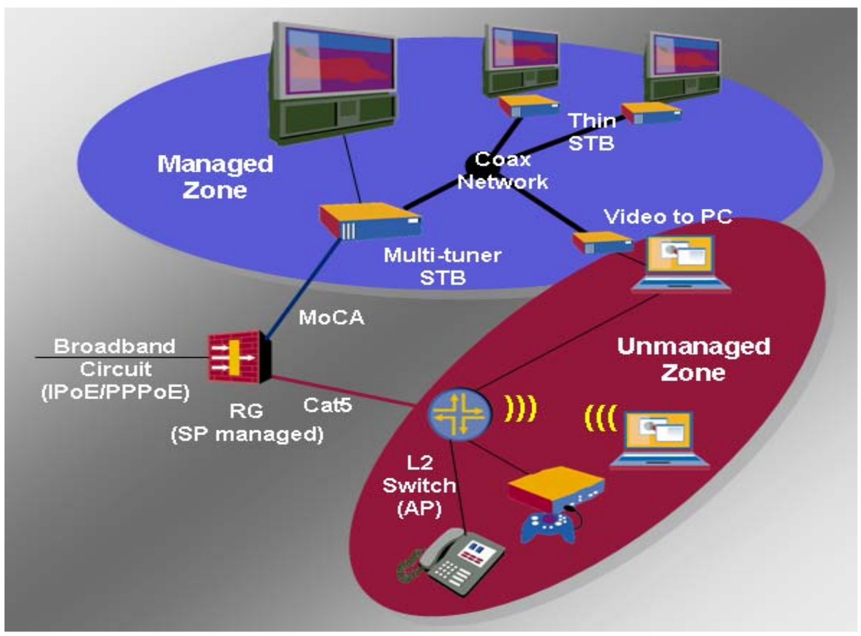


Figure 4: Sample broadband connected home network

This type of home network allows the consumer electronics market to expand and adopt new trends as seen with Internet and in-home services today, but with the added capability of non-best-effort service offerings. However, the home network and access network must be in unison to allow for this type of service evolution to guarantee that more demanding applications have proper packet handling for an acceptable user experience.

IP Convergence in the Access Network

As the home network continues to evolve to IP, how will the access network be constructed to handle the next generation of IP services? One model is to focus mainly on broadcast video with limited bandwidth allocations or control given to non-video applications. The second is to build a robust edge network that is flexible enough to handle the current triple play while easily migrating to the next generation of services.

The first type of model is best characterized by the current HFC architecture shown below in Figure 5. Although highly efficient for broadcast TV delivery, this architecture requires the delivery of all channels into the access network and possibly to the home even if no channels are being viewed. The HFC network is capable of several Gigabits of bandwidth, but only a small percentage is allocated for per-user services such as VoD and Internet. This model has been replicated in some FTTP and xDSL deployments with a heavy emphasis on broadcast video.

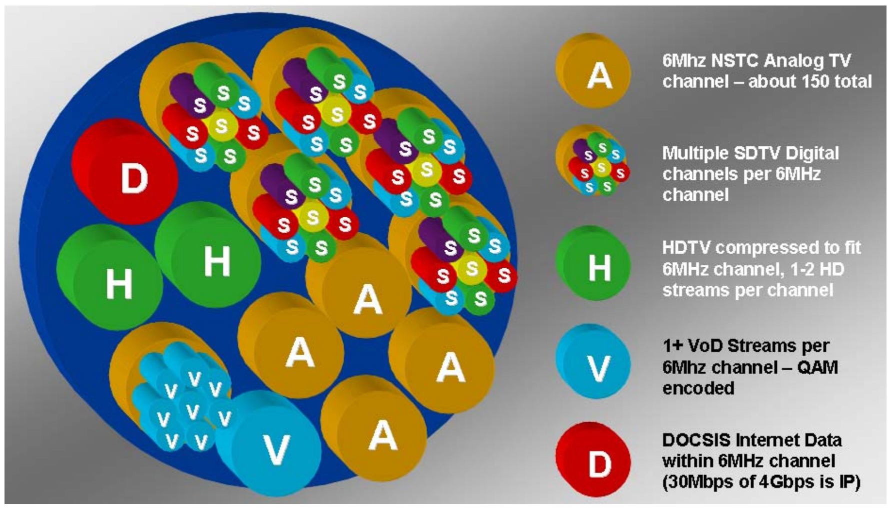


Figure 5: Logical view of an HFC connection, V and D are unicast

This delivery architecture is inconsistent with consumer electronics trends which are migrating away from broadcast TV and focusing more on unicast streaming media. This is evident as the cable operators push to a next generation HFC architecture that enhances the ability to provide per-subscriber delivery of IP application flows in lieu of a high abundance of broadcast television. To offer the full array of services, the IP delivery to the home must shift from a basic Internet offering to a flexible, full service delivery connection. This now places more emphasis on the IP portion of the broadband connection for service delivery.

Switched digital video helps to eliminate the full broadcast of video channels out to the edge of the network by utilizing efficient multicast techniques, but care must be given to the delivery of all services over a single connection. In the traditional IP service offering, Internet was the only service delivered as IP to the home and sold as a best-effort bandwidth allocation to the user. With the convergence of IP services, bandwidth and subscriber management become more critical. Instead of offering a bandwidth to the user that is blind to the application sessions, the new networks must become more involved in the content delivered for QoS treatment as shown in Figure 6 below. This means the network must gain visibility to these traffic flows for each user for service differentiation. Even if the access network link speed is deemed sufficient to handle average application flows, there are still shaping requirements per user based on contracted speeds, last mile speed limitations, and microbursts found in most IP applications that can lead to momentary network congestion.

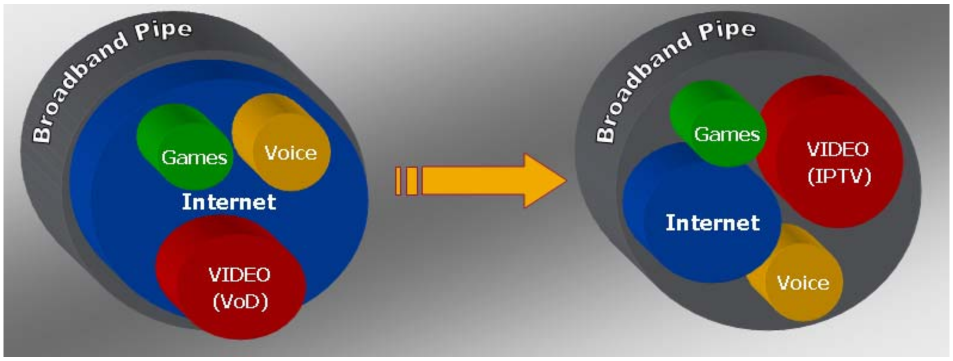


Figure 6: The network evolves to a broadband services portfolio

Instead of breaking the network into specific service offerings or discrete video channels, each user is given a portion of the network with dynamic QoS and service allowances as shown in Figure 7. Here broadcast TV is sent into the network as IP multicast with only the viewed channels sent to the access network. Subscriber interfaces map to the logical bandwidth allowance per home. This limit is set by contracted speeds, physical last mile limitations (xDSL and DOCSIS), or equal sharing of available bandwidth. The key is that users are given a minimum of bandwidth to achieve user fairness along with prioritization of traffic to give the proper experience expected for each application.

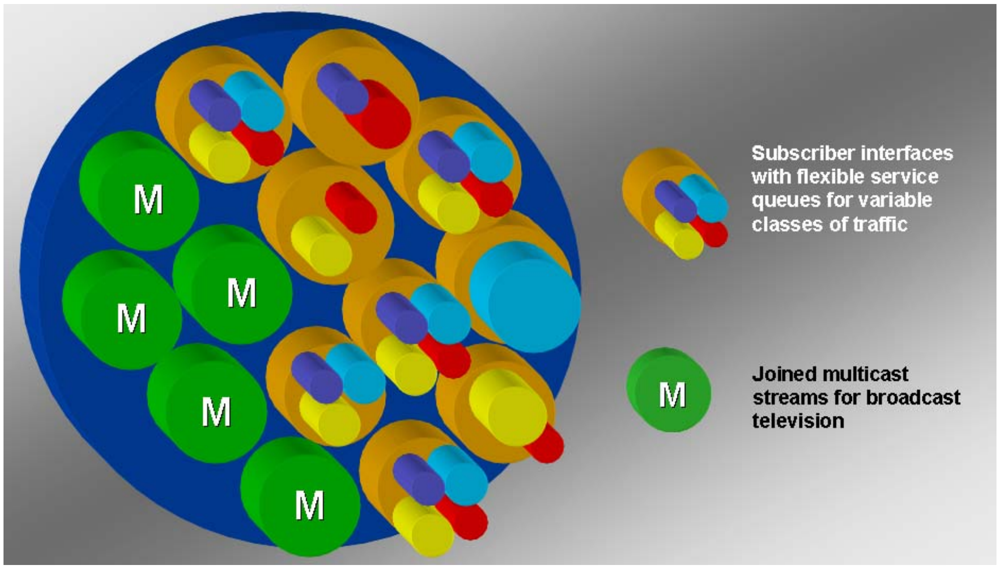


Figure 7: Per-User Visibility and Service Control

This model becomes more fluid without hard service bandwidth allocations. As user trends shift to more unicast or new applications, the access connection is allowed to adapt accordingly to provide more efficient service creation. This does however require a single IP edge point to provide per-user fairness and quality of service control and creates the need for an intelligent broadband edge node that handles admission control, QoS, security, and packet forwarding for all IP services. The edge node must have awareness of all subscriber and application flows to properly manage the link out to the edge of the network.

In addition, this model allows the Service Provider to leverage a common delivery model across multiple access types. Support for both legacy services and emerging technologies will allow Service Providers to serve broader markets and capitalize on new technologies and content relationships without fundamentally changing their broadband architecture. In effect, Service Providers will be able to separate the traditional bond between applications and the network.

The Broadband Services Edge

The Broadband Services Edge is viewed as low-cost distributed access devices (RF switch, DSLAM, OLT/ONT) coupled with an IP intelligent aggregation node. This is analogous to current carrier-grade router designs with the separation of control and forwarding planes. This separation allows for the "brain" of the router to handle more complex processing functions in a centralized location and offload the requirements of the distributed forwarding elements to more rudimentary forwarding tasks such as bridging and basic multicast replication.

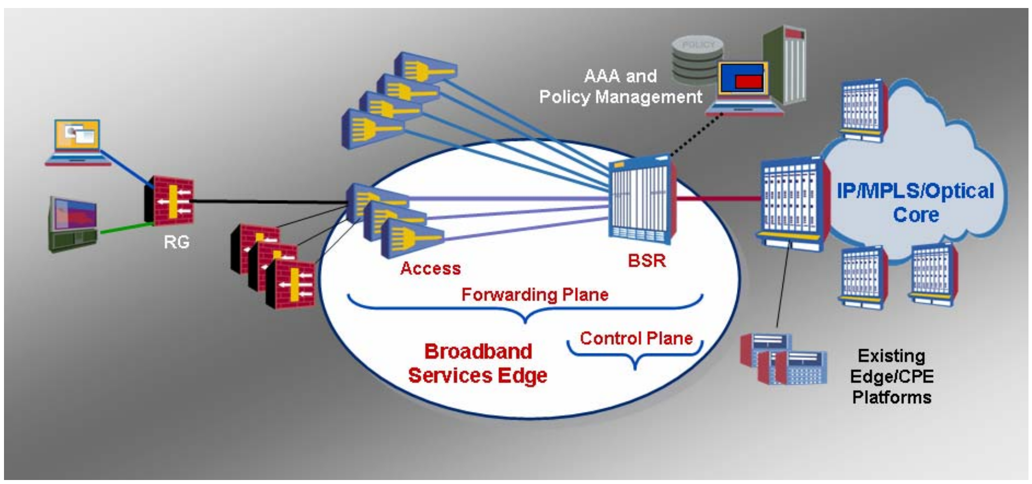


Figure 8: The Broadband Services Edge

The control plane functions of the Broadband Services Edge are performed by the Broadband Services Router (BSR) in conjunction with a policy management platform while the edge elements provide simple forwarding functions and the conversion to the last mile media type. This allows the Service Provider to deploy low cost edge elements with limited functionality in an effort to reduce both capital and operational expenditures. The BSR also becomes a central control point for service creation, Lawful Intercept, policy control, trouble resolution, and integration to back office systems for provisioning, RADIUS events, DHCP events, and logging. These savings increase with the number of remote edge units deployed in the field and allow Service Provider to quickly evolve along with emerging access technologies.

The BSR will aggregate all user sessions and provide subscriber management. A customer VLAN (C-VLAN) is mapped between the BSR and RG per residential connection. This provides visibility to each subscriber, device, and application for accounting, troubleshooting, and policy attachment. The BSR can also act as the multicast router to efficiently deliver both multicast and unicast flows over a single connection to the edge device. The BSR can use a separate multicast VLAN (M-VLAN) if downstream nodes are capable of IGMP snooping and multicast replication. The same capabilities can also apply to ATM for Service Providers that have not made the full transition to Ethernet.

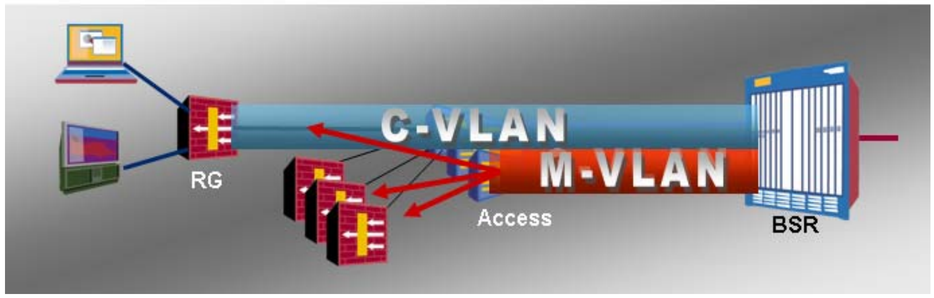


Figure 9: Logical view of C-VLAN and M-VLAN termination on the BSR

The C-VLAN's and the M-VLAN can then easily map into a QoS hierarchy. Each C-VLAN can be shaped based on the current contracted rate to the home (private or wholesale) or based on the physical media speed such as the DSL synchronization rate. The IP QoS layer can then provide policy, shaping, prioritization, and accounting on a per-session or service class basis. Additional hierarchies such as VLAN stacking may be utilized if there is an Ethernet switch or similar aggregation device between the BSR and edge node. This allows for bandwidth allocations per edge device and fairness across the elements. An example of this type of queuing structure is shown below.

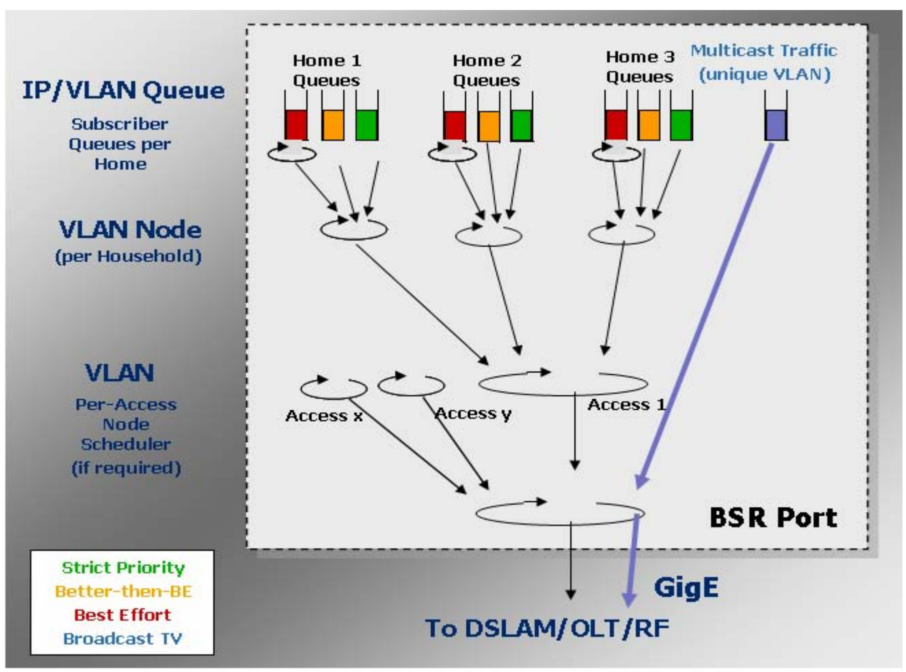


Figure 10: Queue allocations and hierarchy in the BSR

This type of queuing configuration is not optimized for a queue per service, but instead a queue per traffic class delivered to a specific subscriber. Many applications such as voice, video, and gaming may consist of various flows spread across multiple traffic classes during a single session for signaling, media delivery, and session management. These cannot be properly handled by a single queue per service or application. The edge element must be intelligent enough to know the traffic class assignment per flow and what type of packet handling is required during the session.

As a centralized element and the control plane device, the BSR can expand to provide an additional set of functionality beyond basic packet forwarding and subscriber management. Types of features included could be Lawful Intercept, Captive Portal, Worm/Virus monitoring, SIP awareness for multimedia sessions, network-based security, flow record generation, application layer control, and a multitude of other features that are part of the packet handling within the network. New features can be added to the centralized BSR without impact to the distributed edge nodes as new market trends dictate.

The BSR also acts as a gateway into the service domains. The BSR is directly connected into the network core to provide for a common infrastructure to handle all services over a common backbone. By providing logical isolation of subscribers over the C-VLAN, logical separation of service domains through virtual routers or VPN technologies, secure access to service domains through policy definitions, and the ability to segment residential and business class traffic through the same access elements, a common IP service control point can be used across all broadband customers. This alleviates the need to partition the access network by service or class of customer.

The Broadband Services Edge model creates a building block model for broadband service delivery. All of the IP capability is centralized in the BSR which allows for a single point of policy control and becomes a focal point for a policy management system. Service delivery is agnostic to the access networks last mile technology, providing the same set of services independent of the physical media or product used to access the home.

Offering Dynamic QoS and Service Control

When investigating quality of service requirements within the network, it is easy to look at QoS as the simple prioritization of packets so that one packet is preferred over another. As an example, VoIP is a higher priority voice flow with strict latency requirements when compared to a best-effort FTP file transfer. The higher priority voice traffic must pass through a switching or routing device with minimal loss and delay should congestion occur in the network. This simple example highlights the fact that QoS is necessary in broadband networks, but doesn't fully cover the entire range of QoS capabilities required within the network to properly deliver all of the broadband services shown previously in Figure 2. QoS is not activated merely to prioritize packets, but also assists with the following:

- Implement shaping of packet flows to prevent bursty traffic from causing momentary congestion in the network as microbursts saturate simple policing nodes leading to packet loss of more predictable or higher priority application flows
- Implement shaping or rate limiting of packet flows that are not desirable in the network such as peer-to-peer, virus, or worm application flows
- Implement shaping or rate limiting to provide a maximum bandwidth allocation to certain traffic classes based on contracted speeds. The best example is limited Internet usage to 3Mbps on a 20Mbps broadband connection.

- Provide multiple traffic classes to share bandwidth between applications
- Provide fairness between users within a single access element or across access elements so that power users to not exhaust all available network resources

It should be evident that QoS is not just a simple prioritization utility, but becomes a critical tool for network control. Correctly implementing QoS into the network is essential to delivery all classes of applications to subscribers over a common infrastructure. The BSR becomes the focal point of ensuring all of the QoS requirements are honored and can be easily provisioned and tuned in a single location

A sample queue hierarchy for QoS in the BSR was shown in Figure 10. Once the BSR is provisioned with the proper queues, shapers, and policies, how is traffic assigned properly into each traffic class and thus queue or shaper? This will either require static configuration in the BSR or some type of network signaling capability to provide not only downstream QoS and control, but upstream awareness as well in the RG. Many of the new generation of applications that providers will want to offer including voice, gaming, and video chat/collaboration are bi-directional and must map application flows to a QoS requirement in each direction. These applications also do not use well-know ports and have port assignments that are ephemeral leading to a signaling model for QoS preferred over static provisioning.

The BSR architecture with a single logical connection per home easily satisfies both dynamic requirements for QoS and full bi-directional network control. The use of a C-VLAN between the BSR and the RG creates a "broadband conduit" that isolates the user along a logical layer 2 path. QoS is constrained to the single VLAN or VC between the BSR and the subscriber's RG. Complex state sharing between multiple edge nodes or multiple VC's is not required. Now a policy management system within the network only has to look at these two IP touch points at the network edge to modify quality of service parameters.

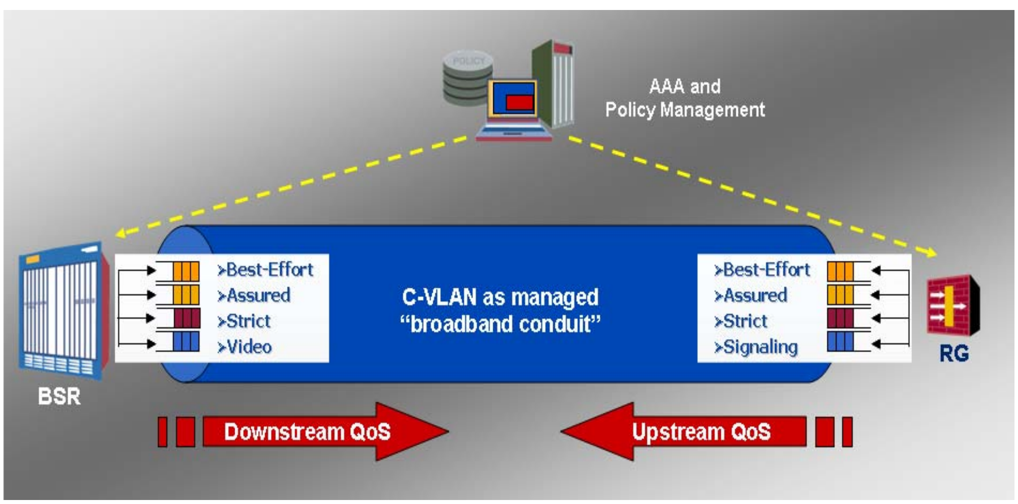


Figure 11: Bi-directional quality of service in the access network

The actual signaling of the network requirements per application is currently being investigated and standardized by several groups including the DSL Forum through TR-59, TR-69, and WT-101 specifications, the Broadband Services Forum with work involving Content Aware Network Signaling (CANS), Cable Labs with PacketCable MultiMedia and

Cable Home initiatives, and 3GPP IMS with broadband and wireless convergence. These standards either provide out-of-band signaling between the policy management system and the BSR or RG through COPS, XML, or other open protocols or use inband signaling capabilities as with the 3GPP IMS use of SIP for all multimedia signaling.

Although provided for different access technologies or application sets, all of these groups have realized the market evolution towards a ubiquitous IP network and are pushing for standardization to allow for ease of use for end-users coupled with dynamic network control of resources. As these standards mature they will provide the underlying framework for QoS and service control in the edge network along with intelligence in the home network devices to enable them to signal application capabilities and quality of service needs on a per session basis.

Summary

There is a rush in the various industries for IP online services including content providers, Service Providers, and consumer electronics companies. This is coupled with the desire for a single broadband provider to the home to offer these IP services.

As the traditional triple play bundle evolves to a commodity offering it will be the unicast service packages that will provide incremental revenue and service differentiation for broadband providers. Service Providers must build their broadband network to be ready for the first generation of triple play while allowing them to extend to more complex offerings without a new buildout of the network.

Acronym List

3GPP	3rd Generation Partnership Project
BSF	Broadband Services Forum
BSR	Broadband Services Router
CANS	Content Aware Network Services
C-VLAN	Customer VLAN
DLNA	Digital Living Network Alliance
DOCSIS	Data Over Cable Service Interface Specification
IMS	Internet Multimedia Subsystem
MoCA	Multimedia Over Coax
M-VLAN	Multicast VLAN
PCMM	PacketCable Multimedia
RG	Routing Gateway
UPnP	Universal Plug-n-Play
VoD	Video on Demand

