The Inktomi® Overlay Solution for Streaming Media Broadcasts

Executive Summary

Streaming audio and video over the Internet holds great promise for service providers looking to add new value-added services. However, to date, technical limitations in distributing and managing live and on-demand Internet broadcasts have stalled the market, with constraints inherent in the design of the Internet being one of the key problems. Equipment providers have attempted to overcome these issues through a variety of approaches; unfortunately, none have succeeded on the scale required to build a sustainable and profitable business.

To truly scale an Internet broadcasting infrastructure to television-sized audiences with television-like quality, multiple service providers specializing in different segments of the content industry must work in concert to build a massively scaled broadcast delivery system.

Inktomi® believes that this delivery system will be based on an overlay to the existing Internet that is optimized for Internet broadcast.

This paper explores the concept of a Media Distribution Network (MDN), the Inktomi model for broadcasting audio and video content over the Internet. Based on a broadcast overlay architecture approach, MDNs feature carrier-grade reliability and scalability, application level multicasting, and policy-based traffic management and control. The broad range of functionality delivered by MDNs allows service providers and content distributors to broadcast thousands of streams to millions of viewers simultaneously.

Inktomi®
essential to the Internet™

Introduction

The Internet's original design is well suited for point-to-point applications like e-mail, file transfer, and Web browsing, but it fails to support large-scale content delivery like broadcast streaming media effectively. For over a decade, the industry has worked to overcome this shortcoming through a technology called "IP multicast," an extension to the IP network layer that provides efficient multipoint packet delivery. However, the reach and scope of IP multicast deployment remains severely limited, damping hopes for Internet broadcasting systems built solely on a global multicast packet service.

Given the absence of a native broadcasting capability in the Internet, streaming-media broadcasters have pieced together various ad hoc distribution systems based on available, off-the-shelf technologies and combined them with proprietary integration technologies. For example, some broadcasters have built distributed server networks using "stream splitters;" others have invested in satellite networks to bypass congested Internet peering points; and still others favor a model based on centralized broadcast centers that attempt to reach subscribers over available private IP multicast paths.

To truly scale an Internet broadcasting infrastructure to television-sized audiences with television-like quality, multiple service providers specializing in different segments of the content industry will work in concert to build a massively scaled broadcast delivery system. However, none of the approaches listed above provides a generally available "broadcast platform" that would allow independent content delivery service providers (CSPs), network service providers, or enterprises to build their own Internet broadcast networks and interconnect them into larger, world-wide broadcast networks that could support thousands of channels to millions of viewers with television-like quality.

The key to enabling this form of cooperation is a new media networking platform that supports "peering relationships" at the streaming media or content distribution layer, where "content backbones" provide "content feeds" to affiliate "content carriers." Much as the Internet is organized as an interconnection of networks enabled through IP-level peering relationships among ISPs, a massively-scaled Internet broadcasting system can be built from interconnecting media distribution networks through higher-level content peering relationships among different types of service providers, including traditional ISPs, content providers, content aggregators, and so forth.

By moving up the protocol stack from the network layer to the content layer, the barriers that have prevented ISPs from establishing network-level multicast peering arrangements evaporate. Deploying Internet broadcasting systems no longer requires new global network services like IP multicast or ubiquitous quality of service. Instead, multicast, quality of service, and such, can be exploited in an application-specific manner; universal deployment isn't required to make the system work.

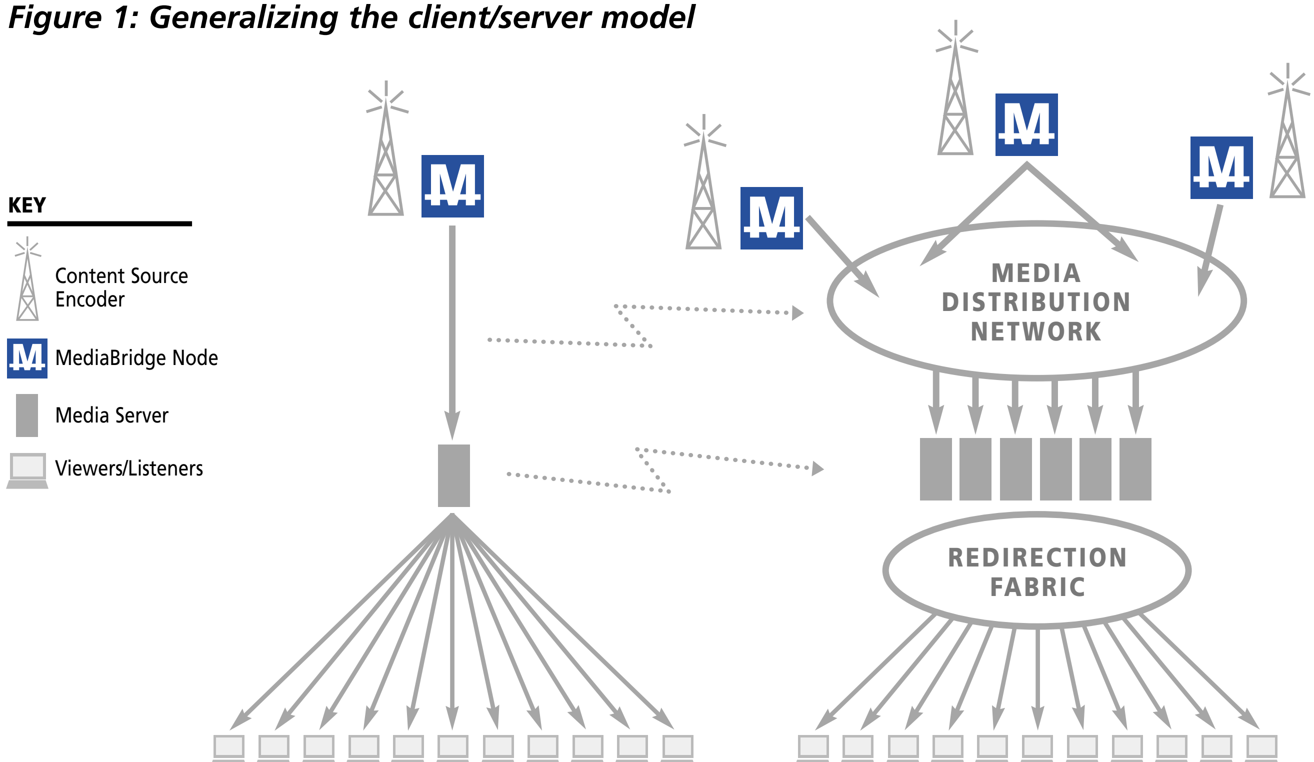
The Media Distribution Network

In support of this emerging content delivery model, Inktomi has developed an approach that ties together a broad range of networking and server technologies into a cohesively managed broadcast network by migrating streaming-media intelligence and control into the network infrastructure. These Media Distribution Networks (MDNs) efficiently route content from streaming-media sources anywhere in the Internet to any number of media servers located at the network edge.

Figure 1 illustrates how an MDN generalizes the traditional client/server model for streaming-media distribution to a system based on the Inktomi platform. The left-hand side of the figure depicts a simple model of the traditional method of acquiring and serving streaming content. Here, a digital media encoder captures an analog audio/video signal, as shown by the broadcast-tower icon. The encoder digitizes, compresses, and packets the signal. From there, the content is delivered to a production server, typically over a simple LAN connection, or from a remote venue like a concert site or sports event across a dedicated link to the production server facility. This dedicated link could be a dial-up ISDN line, a dedicated T1 line, a satellite feed, or a frame relay connection. Once the broadcaster has published content on the production server, any client on the Internet can access the channel with a Web or streaming-media connection from the server to the desktop.

Naturally, this model does not scale. Because each client creates a connection to the server, client requests can easily overwhelm the servers—especially when serving up popular content. Synchronized client access escalates

Figure 1: Generalizing the client/server model



the load problem, e.g., for a live event, and the server ends up sending a separate copy of the content to each requesting client. In addition to overwhelming the server, synchronous access places a heavy burden on the network by forcing it to carry the same content across the same physical links many redundant times.

An MDN overcomes these scaling limitations by extending the client/server model into a broadcast network as shown in the right hand side of Figure 1. This framework generalizes the connection between the injection point and the server into a scalable application-level MDN, where content can be injected at any attachment point in an overlay network of broadcast points of presence (PoPs). These broadcast PoPs are coordinated across the wide area by a sophisticated set of protocols and algorithms that carry out application-level multicast, media traffic control, and intelligent stream management. By bringing together a range of new technologies specifically designed for stream transport, this overlay network can carry content efficiently and reliably from an injection point anywhere in the Internet out to a massively scaled deployment of servers distributed across all the ISP networks covered by the MDN.

Incremental Deployment over the Heterogeneous Internet

By adopting an architecture based on servers at the "edge of the network," an MDN can be built out incrementally to scale with increasing user demand by continually expanding the edge outward. In this approach, servers initially are placed deep in the network, perhaps in a relatively small number of ISP co-location facilities. Over time, as the MDN carries more traffic, servers can be pushed out incrementally toward the edge of the IP network: from the co-locations, into the core, out toward access PoPs, to the DSL aggregation routers, and ultimately to access devices in the central offices and cable head-ends. Dramatic enhancements in network and stream-delivery performance occur when combined with a redirection system that scales with this degree of penetration—even as stream bit-rates rise to broadband levels to provide TV-like quality. Moreover, by adopting a common platform, access network providers, ISPs, and content delivery networks can work together to reach the largest audiences possible at the highest level of stream quality.

The MDN routes content at the application layer, affording a rich and extensible platform for streaming media distribution and management. Broadcasters can build an MDN using different networking and server technologies in different parts of the Internet. For example, in one part of the network, a community of broadband cable-modem users may receive traffic over a localized multicast transmission. In another part of the network, DSL users receive broadband feeds via unicast from a media server located near an aggregation router. And, in another part of the network, dialup users receive 56K feeds from media servers in co-location facilities. Similarly, the core of the distribution may be carried out in some regions using localized multicast deployment across an ISP's backbone, in other regions using a satellite transmission hop, and still in other regions using replicated unicasts between peering broadcast PoPs.

Gluing together these broad and diverse network configurations forms an MDN—a uniform and comprehensive broadcasting system for the service provider. The difficult and complex problem of monitoring and managing a streaming-media network is solved by decomposing the system into the new broadcast layer that rides atop the existing IP layer. Thus, management of the MDN and the underlying network can be separated into a broadcast operations center (where experts in streaming media broadcast operate the MDN) and a network operations center (where experts in IP routing and forwarding technologies run the underlying IP networks). Interactions between the MDN and underlying network mechanisms like IP Multicast, transit IP connectivity, and MPLS can be carried out as needed to provision capacity according to traditional IP service-level agreements.

The Product Suite

To build an MDN that provides these powerful new benefits, a service provider deploys Inktomi products in flexible overlay configurations across the network infrastructure, in operations centers, and on content provider premises. The four core products are:

- *MediaBridge*™ software — an application-level broadcast node that is the principal building block of an MDN.
- *MediaBridge ServerLink software* — a media-specific module for channeling external formats (e.g., Windows Media Technology, RealNetworks G2, Apple QuickTime and AOL Shoutcast into and out of an MDN.
- Traffic Server® Media-IXT™ — a content cache for on-demand broadcasts, situated at the edge of the network.
- The *Broadcast Manager*™ *Suite* — network monitoring and management tools that enable service providers and content distributors to control, view, and monitor broadcasts at the stream level.

The Broadcast PoP

The basic unit of the MDN broadcast network is a collection of software and hardware devices that comprise the "broadcast PoP." Within a broadcast PoP, a number of devices work together to carry out the core functions of the MDN: MediaBridge software pulls streaming feeds into the PoP across the wide area; MediaBridge ServerLink software routes these feeds into media servers; servers transmit streams to end clients; redirection devices perform local server load balancing and wide area redirection functions; client statistics are monitored and logged, monitoring agents probe the health of the PoP and publish this information to the MDN; and so forth.

How and where broadcast PoPs are deployed depends on the design goals for the MDN and is a flexible aspect of the Inktomi overlay solution. Depending on the MDN design, broadcast PoPs can be situated in a number of strategic locations in the IP network architecture, including ISP co-location facilities, data centers, peering sites, content provider broadcast centers, access network headends (e.g. cable network headends or IP-enabled DSL headends), and enterprise backbones.

Figure 2 illustrates the conceptual layout of a broadcast PoP. The left half of the diagram depicts an MDN as a cloud of interconnected broadcast PoPs in a mesh configuration across the wide area. The magnified PoP on the right half of the diagram depicts two MediaBridge nodes feeding three MediaBridge ServerLinks in a fully connected configuration across the local area. With this configuration, if either MediaBridge node is deliberately brought out of service or fails inadvertently, the system automatically reverts to the alternate path and thus recovers without operator intervention.

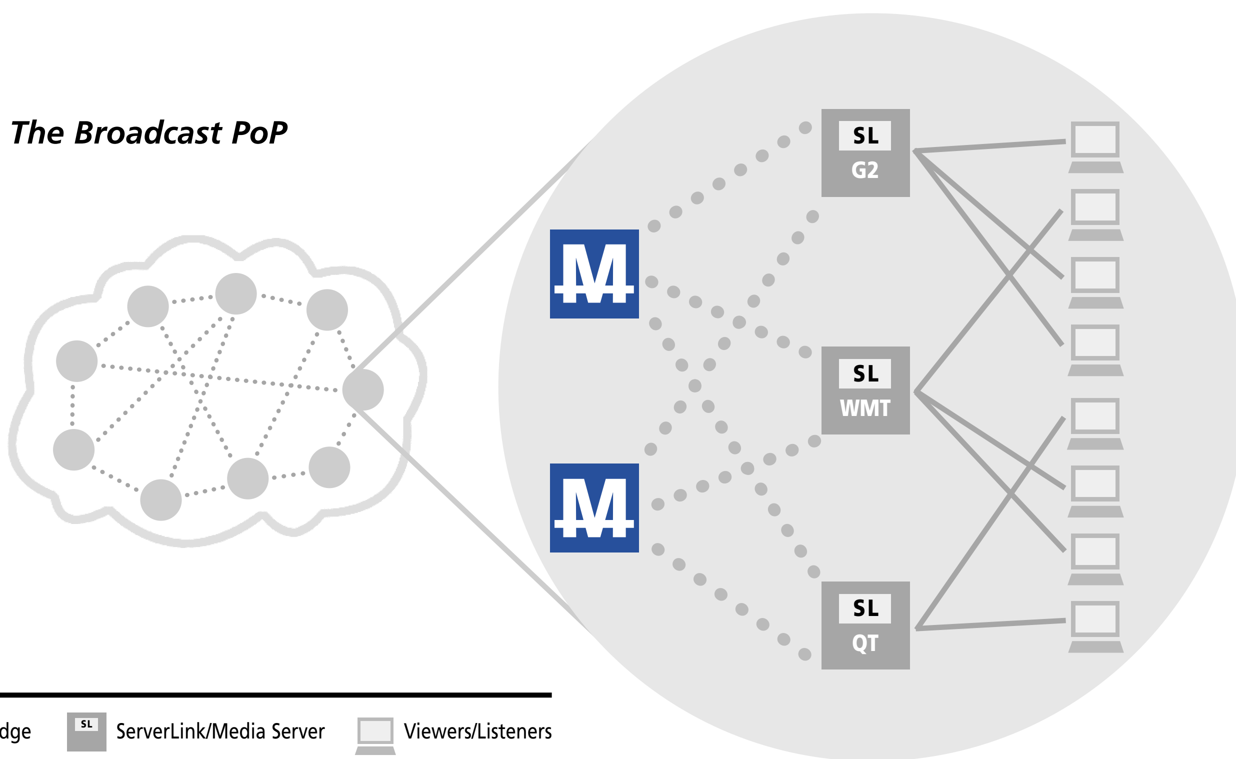
Like streaming media servers, MediaBridge software and MediaBridge ServerLinks that run on a variety of system platforms including Solaris, Linux, and Windows NT. In a typical broadcast PoP, providers allocate one or two Unix hosts to run the MediaBridges and allocate a separate, dedicated Unix or NT host for each media server. The MediaBridge ServerLink runs on the same machine as its corresponding server, and other management processes and agents run across a combination of the hosts to support the MDN management system.

While the Inktomi products form the core of the MDN, they do not directly provide media-serving capabilities to clients. Instead, third-party systems serve content at the edge of the MDN. To integrate these servers at the edge, each MediaBridge ServerLink interconnects the MediaBridge nodes to one or more unmodified media servers, such as the RealNetworks G2 server, the Windows Media Technologies (WMT) server, or the Apple QuickTime server.

Because off-the-shelf media servers are utilized in the broadcast PoPs, the Inktomi solution works completely backward, and is compatible with existing streaming media protocols, servers, and clients like WMT, G2, QuickTime, and Shoutcast. Thus, to the user, an MDN looks just like any other server on the Internet and requires no special configuration, custom software on the client, or user intervention.

A MediaBridge node in a broadcast PoP is classified as an *ingress*, *egress*, or *transit* device based on whether it accepts injection feeds at the entrance to an MDN, serves end-client streaming feeds at the edge of the MDN, or provides transit connectivity between adjacent broadcast PoPs, respectively. At both ingress and egress MediaBridge nodes, MediaBridge ServerLinks provide the glue between third-party servers and encoders and the MDN. Broadcasters can configure any MediaBridge to provide any or all of the ingress, egress, and transit functions.

Figure 2: The Broadcast PoP



To create an event, a content provider configures an off-the-shelf media encoder to inject the feed into one or more MediaBridge nodes. For the most part, Inktomi has automated the process of creating a content feed through its Broadcast Manager Suite of tools described later. As long as the content feed is active, any MediaBridge node in any part of the MDN can subscribe to the feed dynamically across the network.

When a user invokes an MDN URL, the redirection system routes the client directly to an available server in one of the egress broadcast PoPs. This causes the client to initiate a control connection to the server using its native protocols (e.g., RTSP for G2 and QuickTime and MMS for WMT). The MediaBridge ServerLink then intercepts the client request and if the corresponding broadcast feed is not yet present at the server, requests it from the incident egress MediaBridge node. In turn, the egress MediaBridge node pulls down the content feed from across the wide area by subscribing to the corresponding MDN broadcast channel.

The Wide Area Architecture

The MediaBridge software housed in the broadcast PoPs described above are interconnected across the wide area to form a broadcast overlay network that routes streaming media feeds from encoders at broadcast centers, content producers' sites (e.g. at a radio station), or anywhere else in the Internet to any server in any broadcast PoP anywhere in the MDN. Unlike approaches based on self-organizing distributed server meshes, the overlay topology of an MDN is explicitly designed by a network architect so that the overlay is deterministically mapped onto the underlying physical network. This facilitates and enhances business-critical processes like capacity planning, network fault isolation and debugging, bandwidth arbitrage, policy-based routing, multipath forwarding, and so forth.

Application-level Multicast

On top of and across this configured overlay topology, MediaBridge software performs routing at the application layer. Each MediaBridge node interconnects with one or more neighboring MediaBridges through explicit configuration. These connections collectively define the overlay topology. Across this topology, the MediaBridge software in an MDN employs a distributed application-level multicast routing algorithm to determine the optimal virtual paths for propagating content throughout the network. When the underlying network fails or becomes overly congested, the MDN automatically and dynamically re-routes content via alternate paths according to application-level routing policies.

Because MediaBridge nodes perform dynamic stream routing, new events do not require that broadcasters explicitly pre-configure every egress MediaBridge with knowledge of these new broadcasts. Instead, egress MediaBridge nodes dynamically subscribe to broadcast content when and only when a downstream client requests it. This MDN-wide capability ensures that one and only one copy of the broadcast content flows across any physical or virtual path—independent of the number of downstream clients—thus conserving network bandwidth.

Although the overlay network topology is fixed, broadcast operators can easily modify and evolve the design as needed. The Inktomi Broadcast Manager Suite provides a comprehensive set of tools and APIs for managing and revising the overlay topology.

AnyEdge™ Injection

One of the most difficult and expensive aspects of many existing Internet broadcast service networks is the signal acquisition mechanism. Broadcasters typically structure broadcast facilities so tall live content originates from a centralized data center, requiring a system design that accommodates the acquisition of live feeds at that facility. Often, broadcasters build a private network using relatively expensive mechanisms for providing guaranteed delivery of live feeds to the broadcast center.

However, Inktomi technology builds the acquisition path into the MDN, making a separate acquisition network unnecessary. Because the MDN is bi-directional, an encoder can attach to an ingress MediaBridge node located anywhere in the network and the content routing system ensures that the stream is delivered to any egress MediaBridge node requesting that stream. In effect, a content producer can broadcast to arbitrarily large audiences simply by connecting to an MDN across a commodity Internet connection that it may already have. As long as the content provider's ISP is covered by the broadcaster's MDN and the access connection is of sufficient bit-rate, the resulting quality is as good as any private acquisition network. Thus, anyone on the Internet with the appropriate encoding software can become an Internet broadcaster through an MDN-enabled content delivery service provider.

Performance and Reliability Benefits

The ability to manage and process streams at the application layer greatly enhances the reliability and delivery performance of an MDN across a number of dimensions. First, because of its ability to perform adaptive routing, an MDN is self-healing. It routes around network or device failures, ensuring that viewers stay connected and have a quality viewing experience. With a proper MDN overlay topology — including multiple paths, multiple injection points, and redundant components — virtually all single points of failure are eliminated, providing unsurpassed reliability and system availability.

Second, by integrating application-level intelligence with routing decisions, an MDN can detect stream outages (e.g., at a satellite downlink) and reroute streams across alternate paths should this occur. An IP routing-based scheme simply cannot achieve this level of resiliency since the routing layer and the application-monitoring layer are completely isolated from one another.

Third, the MediaBridge software has per-stream traffic shaping abilities that greatly enhance performance. MediaBridge software shapes a stream at each hop in the overlay network, eliminating traffic bursts that would otherwise cause transient congestion and packet loss in the network.

Finally, unlike IP routers, MediaBridge nodes perform rate-constrained retransmissions on each hop in the overlay network to provide an extremely reliable transport system. To accomplish this, MediaBridge software buffers some of each stream's history and retransmits lost packets as necessary to ensure high quality. Even with this extra buffering, however, end-to-end delay is minimized because MediaBridge software performs cut-through routing by forwarding packets as soon as possible. Moreover, broadcasters can carefully control the bandwidth used by retransmissions through administratively defined traffic management policies. As retransmission bandwidth increases to counteract packet losses, the quality of the delivered streams is modulated such that the best possible stream quality is delivered for a given level of congestion and allocated bandwidth.

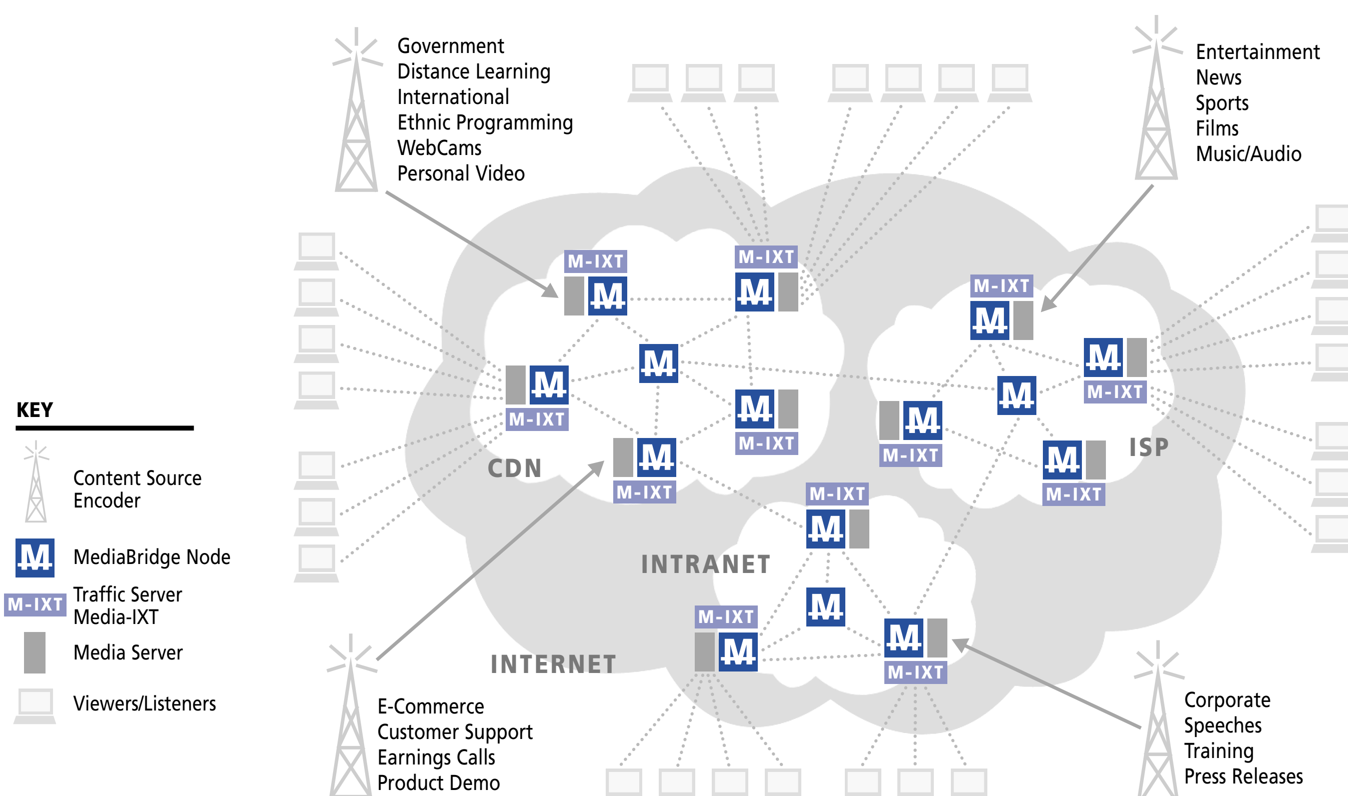
MDN Provisioning and Deployment

Illustrating the power, flexibility, and manageability that an MDN provides, Figure 3 depicts one possible configuration of broadcast PoPs in an overlay topology. Many other network configurations are possible, of course, but this example highlights how a high-quality and reliable MDN can be built and deployed across today's Internet with today's Internet service offerings and business practices. This small-scale scenario can clearly be generalized into a much larger MDN by replicating and extending the design across additional networks.

In this figure, there are four routing domains or "autonomous systems" labeled AS100, AS200, AS300, and AS400. In addition, there is a private point-of-presence, which might be built in a private physical facility or co-located with other service providers at a public Internet business exchange point. The service provider purchases transit IP connectivity into various ISP networks from this private broadcast PoP, receiving a guaranteed bandwidth into and out of each ISP network. Because each ISP typically provides excellent service-level agreements for communication between any two hosts within its network, the well-connected PoP can reach other broadcast PoPs within the same network with very high performance.

As shown in the diagram, MediaBridge software and media servers are deployed in broadcast PoPs across AS100, AS300, and AS400. The physical peering connections between the routing domains are shown as a thick solid line, while the virtual links comprising the MDN overlay topology are depicted as light, dashed lines. Finally, content providers producing active streams are attached to several locations as depicted with the broadcast-tower icons.

Figure 3: The Broadcast Internet



Omitted from the diagram is the redirection system that routes each client request for a stream to an appropriate server. Service providers can choose either to custom design the technology with optional assistance from Inktomi or purchase it from a third-party vendor. This redirection system routes clients in an AS to an appropriate broadcast PoP, which typically lies within the same AS as the requesting client. For example, clients in AS300 are routed to servers in AS300, clients in AS400 are routed to servers in AS400 — but if all the servers in an AS become overloaded, clients may be directed elsewhere. For clients on ISPs not covered by the MDN, e.g., AS200, various techniques have been developed to determine which AS covered by the MDN should be used to serve the requesting client, e.g. by building Internet topology maps based on BGP routing tables. Many options and approaches are available to solve these problems and fall outside the scope of our product offerings.

Constructing the MDN in this fashion gives the service provider complete control of the quality of delivered streams across the broadcast network because streams do not touch Internet peering points. Rather than interconnect MediaBridge nodes across uncontrollable peering points, within this MDN all transit paths involve only MediaBridge nodes that are located within the same routing domain. In this case, the standard service-level agreements provided by ISPs offer predictable bandwidth (the line rate) and very low packet loss rates. Where Internet peering is a necessity, MediaBridge software retransmits to recover from congestion and notifies the broadcast operator when the underlying network performance is too poor to repair.

Given the flexible software nature of the MDN and broadcast PoPs, the broadcast operator can easily control where and how traffic is routed across the overlay topology in a rich, policy-aware fashion. For example, by situating a large number of private broadcast PoPs in different parts of the world with rich interconnects into many different ISPs, the MDN can quickly be reconfigured to improve or alter the topology as bandwidth costs and needs evolve. By relying upon multiple carriers for wide-area bandwidth, the broadcast service provider can arbitrage among them to minimize cost.

In short, this deployment model allows service providers to build MDNs that completely bypass congested Internet peering points, ensuring loss-free stream delivery from any injection point to all edge servers in the MDN.

Policy-based Broadcast Traffic Management

To ensure predictable and high-quality streaming transport, an MDN offers a rich spectrum of tools and mechanisms for application-level traffic management and monitoring. MediaBridge software, in particular, intelligently shapes traffic and thins streams at each hop in the overlay network in accordance with customer-specific management policies. With these capabilities, the service provider can assign a bandwidth allotment to each of its customers, then configure its MDN with rules to bind each customer's traffic to the appropriate class.

Intelligent Stream Thinning

When a customer creates a new event and injects a new content feed, the MDN automatically ensures that adequate bandwidth resources are available for each provisioned channel. If, however, a customer's stream overruns its prescribed bandwidth allotment either deliberately or inadvertently, MediaBridge nodes perform "intelligent stream thinning" to groom the flow rather than drop packets indiscriminately. This mechanism intelligently drops select packets to fit within the allotted bandwidth, reducing the stream's bit-rate. MediaBridge nodes understand the format and structure of the underlying media streams so packets can be dropped in a way that gracefully degrades the stream's quality instead of corrupting the flow outright.

Because of these controls, a misbehaving feed can do no harm to any other customer's traffic, allowing a service provider to offer rich service level agreements (SLAs) to its content-producing customers and honor those SLAs with confidence.

Exploiting Network-level Quality of Service

Even if the MDN carefully shapes traffic at each virtual hop in the overlay network, there is no explicit guarantee that the underlying IP network will provide the performance necessary to support the MDN customer policies. For portions of the underlying network that are private and/or provisioned adequately, the MDN's bandwidth policies are fully guaranteed. But for portions of the MDN that cross the public Internet or cross transit links that are shared with other heavy forms of traffic (e.g., production Web traffic), stream-delivery performance can suffer as a result of unrelated network congestion.

To overcome this problem, the MDN can be designed to account for provisioning and quality-of-service capabilities in the underlying IP networks, providing arbitrarily high broadcast quality. When and where needed, an MDN can exploit network bandwidth provisioning mechanisms like MPLS and Differentiated Services. Because MediaBridge software implements traffic prioritization and bandwidth allocation, it can effectively utilize underlying network Quality of Service, if available. For example, broadcasters can configure a virtual link in an MDN as an MPLS label-switched path (LSP). Then, MediaBridge nodes can route and manage streams across that LSP according to the locally defined stream policies. Similarly, MediaBridge traffic classes could potentially be marked as high-priority and low-priority, thereby causing the appropriate bits in the IP header to be marked in accordance with locally deployed Differentiated Services network.

In short, this overall architecture for streaming bandwidth management provides an elegant solution to the quality-of-service problem. There is no need to modify existing applications nor is it necessary to deploy end-to-end quality-of-service throughout the Internet. Instead, MediaBridge nodes act as transparent intermediaries between the streaming media applications and the underlying network quality-of-service mechanisms in accordance with the policies defined and enforced by the MDN.

Broadcast Publishing and Management

One of the most important components of a successful Internet broadcast service is a broadcast operations center (BOC) that has complete control and knowledge of the running broadcast network at many levels of detail. All of the powerful features and capabilities of an MDN would be fairly useless if such a BOC could not be built or if the system were difficult to configure and manage. Because of this, Inktomi has invested significant development resources into designing and building a rich, easy-to-use, and extensible management platform for configuring, running, and monitoring an MDN. This platform includes a broad and growing set of tools and techniques for managing both an MDN and the content published into and across it.

Inktomi's management tools, embodied in the Broadcast Manager Suite, make it easy to configure the MDN, publish events, monitor performance aspects of the running MDN, collect viewer activity statistics for capacity planning, perform billing, and so forth. Managing multiple streaming-media formats and technologies from a single system eliminates the headaches of server configuration across multiple platforms. Broadcasters can detect, diagnose, isolate, and correct broadcast problems from a centralized broadcast center.

A set of configuration tools gives the broadcast architecture and operations personnel a solid foundation to configure and manage the layout and design of MDNs. Definition of the broadcast overlay topology and configuration information lies in XML-based configuration files manipulated and distributed across the wide area with command-line tools.

In contrast, broadcasters conduct monitoring and other day-to-day operations through Web-based tools based on a rich, extensible, and customizable platform for broadcast management that typically run in the operations center. The MDN exports an open API for managing and controlling its infrastructure so it is possible to customize management tools for a particular broadcaster's needs.

The Broadcast Manager Suite's Web interface allows a broadcast operator to manage, monitor, debug, and adjust traffic policies across a running MDN. This tool runs as an agent, typically on a dedicated host in a broadcast operations center. In the background, the manager agent monitors the MDN by communicating with network agents situated on MediaBridge nodes and within MediaBridge ServerLink software. The manager host exports a Web-based user interface that is compatible with any standard Web browser. Using the Broadcast Manager Suite, a broadcast operator can monitor the health of the network using application-level metrics in real-time, reconfigure links, spot traffic problems, monitor utilization, and so forth.

Summary

The Internet promises to revolutionize the delivery of mainstream television and radio by leveraging the flexibility, scope, and reach of IP. Yet, before the Internet subsumes traditional television and radio broadcast networks, the difficult scaling and management problems facing Internet broadcasters today must be overcome.

The Inktomi broadcast platform, as embodied in our Media Distribution Network architecture, provides the answers. As described in this white paper, Inktomi has introduced a number of new, innovative technologies that collectively convert the Internet to a broadcast medium, including application-level multicast, intelligent stream management and routing, flexible traffic policies, and sophisticated, yet easy-to-use, management and configuration tools. By synergistically integrating these new technologies with existing technologies like third-party media servers, IP multicast, network Quality of Service, and redirection, Inktomi not only empowers broadcast service providers with the ability to bring highly manageable, large-scale broadcast services to market quickly, but also instills in these service providers the confidence that their networks will scale with the exponentially growing demand that is now upon the Internet broadcast industry.