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Use of Multicast across Inter-domain Peering Points

Abstract

This document examines the use of Source-Specific Multicast (SSM) across inter-domain peering points for a specified set of deployment scenarios. The objectives are to (1) describe the setup process for multicast-based delivery across administrative domains for these scenarios and (2) document supporting functionality to enable this process.

Status of This Memo

This memo documents an Internet Best Current Practice.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on BCPs is available in Section 2 of RFC 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at https://www.rfc-editor.org/info/rfc8313.

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1. Introduction

Content and data from several types of applications (e.g., live video streaming, software downloads) are well suited for delivery via multicast means. The use of multicast for delivering such content or other data offers significant savings in terms of utilization of resources in any given administrative domain. End User (EU) demand for such content or other data is growing. Often, this requires transporting the content or other data across administrative domains via inter-domain peering points.

The objectives of this document are twofold:

- Describe the technical process and establish guidelines for setting up multicast-based delivery of application content or other data across inter-domain peering points via a set of use cases (where "Use Case 3.1" corresponds to Section 3.1, "Use Case 3.2" corresponds to Section 3.2, etc.).

- Catalog all required exchanges of information between the administrative domains to support multicast-based delivery. This enables operators to initiate necessary processes to support inter-domain peering with multicast.

The scope and assumptions for this document are as follows:

- Administrative Domain 1 (AD-1) sources content to one or more EUs in one or more Administrative Domain 2 (AD-2) entities. AD-1 and AD-2 want to use IP multicast to allow support for large and growing EU populations, with a minimum amount of duplicated traffic to send across network links.

  * This document does not detail the case where EUs are originating content. To support that additional service, it is recommended that some method (outside the scope of this document) be used by which the content from EUs is transmitted to the application in AD-1 and AD-1 can send out the traffic as IP multicast. From that point on, the descriptions in this document apply, except that they are not complete because they do not cover the transport or operational aspects of the leg from the EU to AD-1.

  * This document does not detail the case where AD-1 and AD-2 are not directly connected to each other and are instead connected via one or more other ADs (as opposed to a peering point) that serve as transit providers. The cases described in this document where tunnels are used between AD-1 and AD-2 can be applied to such scenarios, but SLA ("Service Level Agreement")

control, for example, would be different. Additional issues will likely exist as well in such scenarios. This topic is left for further study.

- For the purposes of this document, the term "peering point" refers to a network connection ("link") between two administrative network domains over which traffic is exchanged between them. This is also referred to as a Network-to-Network Interface (NNI). Unless otherwise noted, it is assumed that the peering point is a private peering point, where the network connection is a physically or virtually isolated network connection solely between AD-1 and AD-2. The other case is that of a broadcast peering point, which is a common option in public Internet Exchange Points (IXPs). See Section 4.2.4 for more details.

- AD-1 is enabled with native multicast. A peering point exists between AD-1 and AD-2.

- It is understood that several protocols are available for this purpose, including Protocol-Independent Multicast - Sparse Mode (PIM-SM) and Protocol-Independent Multicast - Source-Specific Multicast (PIM-SSM) [RFC7761], the Internet Group Management Protocol (IGMP) [RFC3376], and Multicast Listener Discovery (MLD) [RFC3810].

- As described in Section 2, the source IP address of the (so-called "(S,G)") multicast stream in the originating AD (AD-1) is known. Under this condition, using PIM-SSM is beneficial, as it allows the receiver’s upstream router to send a join message directly to the source without the need to invoke an intermediate Rendezvous Point (RP). The use of SSM also presents an improved threat mitigation profile against attack, as described in [RFC4609]. Hence, in the case of inter-domain peering, it is recommended that only SSM protocols be used; the setup of inter-domain peering for ASM (Any-Source Multicast) is out of scope for this document.

- The rest of this document assumes that PIM-SSM and BGP are used across the peering point, plus Automatic Multicast Tunneling (AMT) [RFC7450] and/or Generic Routing Encapsulation (GRE), according to the scenario in question. The use of other protocols is beyond the scope of this document.

- AMT is set up at the peering point if either the peering point or AD-2 is not multicast enabled. It is assumed that an AMT relay will be available to a client for multicast delivery. The selection of an optimal AMT relay by a client is out of scope for

this document. Note that using AMT is necessary only when native multicast is unavailable in the peering point (Use Case 3.3) or in the downstream administrative domain (Use Cases 3.4 and 3.5).

- It is assumed that the collection of billing data is done at the application level and is not considered to be a networking issue. The settlements process for EU billing and/or inter-provider billing is out of scope for this document.

- Inter-domain network connectivity troubleshooting is only considered within the context of a cooperative process between the two domains.

This document also attempts to identify ways by which the peering process can be improved. Development of new methods for improvement is beyond the scope of this document.

2. Overview of Inter-domain Multicast Application Transport

A multicast-based application delivery scenario is as follows:

- Two independent administrative domains are interconnected via a peering point.

- The peering point is either multicast enabled (end-to-end native multicast across the two domains) or connected by one of two possible tunnel types:

  * A GRE tunnel [RFC2784] allowing multicast tunneling across the peering point, or

  * AMT [RFC7450].

- A service provider controls one or more application sources in AD-1 that will send multicast IP packets via one or more (S,G)s (multicast traffic flows; see Section 4.2.1 if you are unfamiliar with IP multicast). It is assumed that the service being provided is suitable for delivery via multicast (e.g., live video streaming of popular events, software downloads to many devices) and that the packet streams will be carried by a suitable multicast transport protocol.

- An EU controls a device connected to AD-2, which runs an application client compatible with the service provider’s application source.

- The application client joins appropriate (S,G)s in order to receive the data necessary to provide the service to the EU. The mechanisms by which the application client learns the appropriate (S,G)s are an implementation detail of the application and are out of scope for this document.

The assumption here is that AD-1 has ultimate responsibility for delivering the multicast-based service on behalf of the content source(s). All relevant interactions between the two domains described in this document are based on this assumption.

Note that AD-2 may be an independent network domain (e.g., a Tier 1 network operator domain). Alternately, AD-2 could also be an enterprise network domain operated by a single customer of AD-1. The peering point architecture and requirements may have some unique aspects associated with enterprise networks; see Section 3.

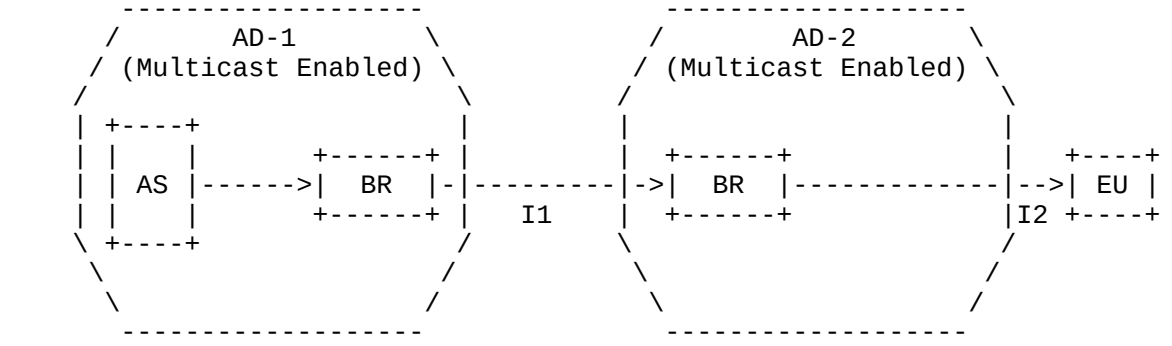
The use cases describing various architectural configurations for multicast distribution, along with associated requirements, are described in Section 3. Section 4 contains a comprehensive list of pertinent information that needs to be exchanged between the two domains in order to support functions to enable application transport.

3. Inter-domain Peering Point Requirements for Multicast

The transport of applications using multicast requires that the inter-domain peering point be enabled to support such a process. This section presents five use cases for consideration.

3.1. Native Multicast

This use case involves end-to-end native multicast between the two administrative domains, and the peering point is also native multicast enabled. See Figure 1.



AD = Administrative Domain (independent autonomous system)
AS = multicast (e.g., content) Application Source
BR = Border Router
I1 = AD-1 and AD-2 multicast interconnection (e.g., MP-BGP)
I2 = AD-2 and EU multicast connection

Figure 1: Content Distribution via End-to-End Native Multicast

Advantages of this configuration:

- Most efficient use of bandwidth in both domains.
- Fewer devices in the path traversed by the multicast stream when compared to an AMT-enabled peering point.

From the perspective of AD-1, the one disadvantage associated with native multicast to AD-2 instead of individual unicast to every EU in AD-2 is that it does not have the ability to count the number of EUs as well as the transmitted bytes delivered to them. This information is relevant from the perspective of customer billing and operational logs. It is assumed that such data will be collected by the application layer. The application-layer mechanisms for generating this information need to be robust enough so that all pertinent requirements for the source provider and the AD operator are satisfactorily met. The specifics of these methods are beyond the scope of this document.

Architectural guidelines for this configuration are as follows:

a. Dual homing for peering points between domains is recommended as a way to ensure reliability with full BGP table visibility.

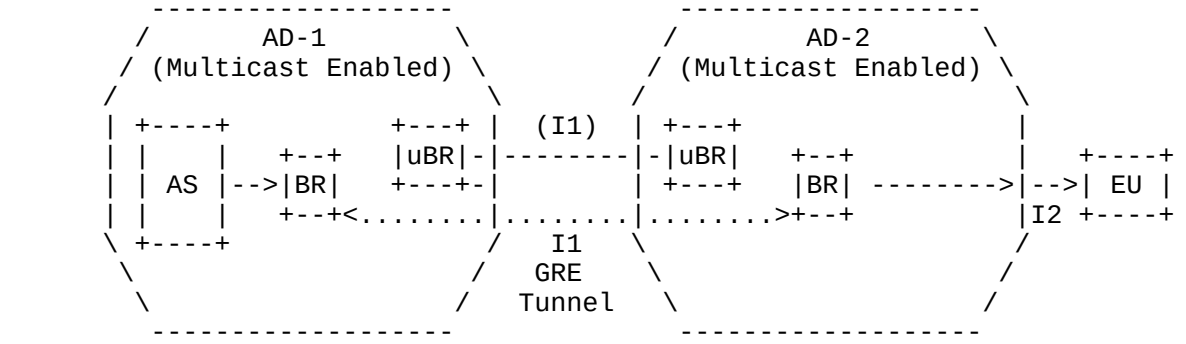
b. If the peering point between AD-1 and AD-2 is a controlled network environment, then bandwidth can be allocated accordingly by the two domains to permit the transit of non-rate-adaptive multicast traffic. If this is not the case, then the multicast traffic must support congestion control via any of the mechanisms described in Section 4.1 of [BCP145].

c. The sending and receiving of multicast traffic between two domains is typically determined by local policies associated with each domain. For example, if AD-1 is a service provider and AD-2 is an enterprise, then AD-1 may support local policies for traffic delivery to, but not traffic reception from, AD-2. Another example is the use of a policy by which AD-1 delivers specified content to AD-2 only if such delivery has been accepted by contract.

d. It is assumed that relevant information on multicast streams delivered to EUs in AD-2 is collected by available capabilities in the application layer. The precise nature and formats of the collected information will be determined by directives from the source owner and the domain operators.

3.2. Peering Point Enabled with GRE Tunnel

The peering point is not native multicast enabled in this use case. There is a GRE tunnel provisioned over the peering point. See Figure 2.



AD = Administrative Domain (independent autonomous system)
AS = multicast (e.g., content) Application Source
uBR = unicast Border Router - not necessarily multicast enabled;
may be the same router as BR
BR = Border Router - for multicast
I1 = AD-1 and AD-2 multicast interconnection (e.g., MP-BGP)
I2 = AD-2 and EU multicast connection

Figure 2: Content Distribution via GRE Tunnel

In this case, interconnection I1 between AD-1 and AD-2 in Figure 2 is multicast enabled via a GRE tunnel [RFC2784] between the two BRs and encapsulating the multicast protocols across it.

Normally, this approach is chosen if the uBR physically connected to the peering link cannot or should not be enabled for IP multicast. This approach may also be beneficial if the BR and uBR are the same device but the peering link is a broadcast domain (IXP); see Section 4.2.4.

The routing configuration is basically unchanged: instead of running BGP (SAFI-2) ("SAFI" stands for "Subsequent Address Family Identifier") across the native IP multicast link between AD-1 and AD-2, BGP (SAFI-2) is now run across the GRE tunnel.

Advantages of this configuration:

- Highly efficient use of bandwidth in both domains, although not as efficient as the fully native multicast use case (Section 3.1).

- Fewer devices in the path traversed by the multicast stream when compared to an AMT-enabled peering point.

- Ability to support partial and/or incremental IP multicast deployments in AD-1 and/or AD-2: only the path or paths between the AS/BR (AD-1) and the BR/EU (AD-2) need to be multicast enabled. The uBRs may not support IP multicast or enabling it could be seen as operationally risky on that important edge node, whereas dedicated BR nodes for IP multicast may (at least initially) be more acceptable. The BR can also be located such that only parts of the domain may need to support native IP multicast (e.g., only the core in AD-1 but not edge networks towards the uBR).

- GRE is an existing technology and is relatively simple to implement.

Disadvantages of this configuration:

- Per Use Case 3.1, current router technology cannot count the number of EUs or the number of bytes transmitted.

- The GRE tunnel requires manual configuration.

- The GRE tunnel must be established prior to starting the stream.

- The GRE tunnel is often left pinned up.

Architectural guidelines for this configuration include the following:

Guidelines (a) through (d) are the same as those described in Use Case 3.1. Two additional guidelines are as follows:

e. GRE tunnels are typically configured manually between peering points to support multicast delivery between domains.

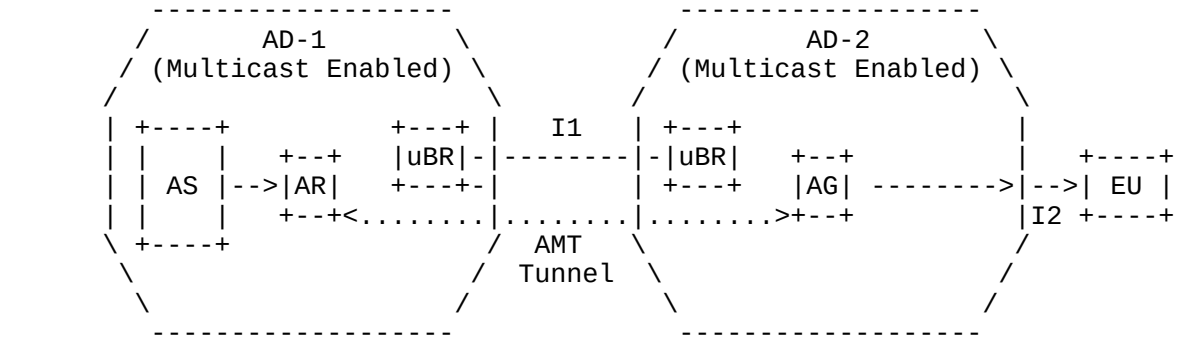
f. It is recommended that the GRE tunnel (tunnel server) configuration in the source network be such that it only advertises the routes to the application sources and not to the entire network. This practice will prevent unauthorized delivery

of applications through the tunnel (for example, if the application (e.g., content) is not part of an agreed-upon inter-domain partnership).

3.3. Peering Point Enabled with AMT - Both Domains Multicast Enabled

It is assumed that both administrative domains in this use case are native multicast enabled here; however, the peering point is not.

The peering point is enabled with AMT. The basic configuration is depicted in Figure 3.



AD = Administrative Domain (independent autonomous system)
AS = multicast (e.g., content) Application Source
AR = AMT Relay
AG = AMT Gateway
uBR = unicast Border Router - not multicast enabled;
also, either AR = uBR (AD-1) or uBR = AG (AD-2)
I1 = AMT interconnection between AD-1 and AD-2
I2 = AD-2 and EU multicast connection

Figure 3: AMT Interconnection between AD-1 and AD-2

Advantages of this configuration:

- Highly efficient use of bandwidth in AD-1.
- AMT is an existing technology and is relatively simple to implement. Attractive properties of AMT include the following:
  - Dynamic interconnection between the gateway-relay pair across the peering point.
  - Ability to serve clients and servers with differing policies.

Disadvantages of this configuration:

- Per Use Case 3.1 (AD-2 is native multicast), current router technology cannot count the number of EUs or the number of bytes transmitted to all EUs.

- Additional devices (AMT gateway and relay pairs) may be introduced into the path if these services are not incorporated into the existing routing nodes.

- Currently undefined mechanisms for the AG to automatically select the optimal AR.

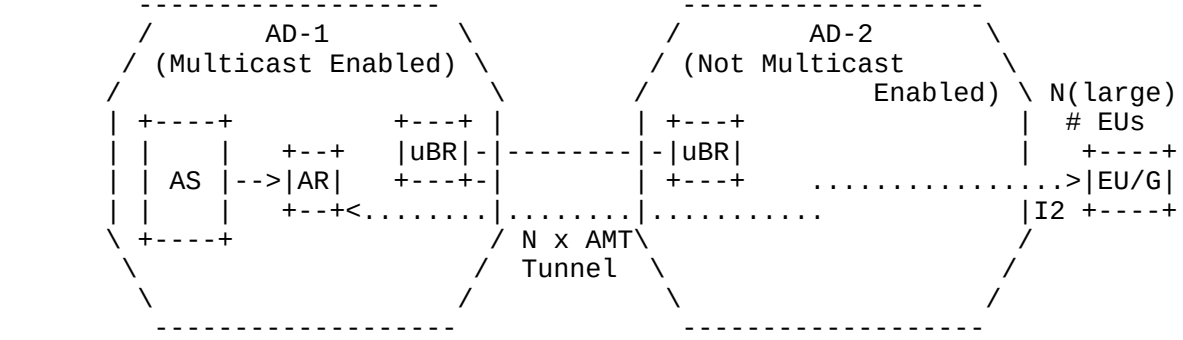
Architectural guidelines for this configuration are as follows:

Guidelines (a) through (d) are the same as those described in Use Case 3.1. In addition,

e. It is recommended that AMT relay and gateway pairs be configured at the peering points to support multicast delivery between domains. AMT tunnels will then configure dynamically across the peering points once the gateway in AD-2 receives the (S,G) information from the EU.

3.4. Peering Point Enabled with AMT - AD-2 Not Multicast Enabled

In this AMT use case, AD-2 is not multicast enabled. Hence, the interconnection between AD-2 and the EU is also not multicast enabled. This use case is depicted in Figure 4.



AS = multicast (e.g., content) Application Source
uBR = unicast Border Router - not multicast enabled;
otherwise, AR = uBR (in AD-1)
AR = AMT Relay
EU/G = Gateway client embedded in EU device
I2 = AMT tunnel connecting EU/G to AR in AD-1 through non-multicast-enabled AD-2

Figure 4: AMT Tunnel Connecting AD-1 AMT Relay and EU Gateway

This use case is equivalent to having unicast distribution of the application through AD-2. The total number of AMT tunnels would be equal to the total number of EUs requesting the application. The peering point thus needs to accommodate the total number of AMT tunnels between the two domains. Each AMT tunnel can provide the data usage associated with each EU.

Advantages of this configuration:

- Efficient use of bandwidth in AD-1 (the closer the AR is to the uBR, the more efficient).
- Ability of AD-1 to introduce content delivery based on IP multicast, without any support by network devices in AD-2: only the application side in the EU device needs to perform AMT gateway library functionality to receive traffic from the AMT relay.
- Allows AD-2 to "upgrade" to Use Case 3.5 (see Section 3.5) at a later time, without any change in AD-1 at that time.

- AMT is an existing technology and is relatively simple to implement. Attractive properties of AMT include the following:
  - Dynamic interconnection between the AMT gateway-relay pair across the peering point.
  - Ability to serve clients and servers with differing policies.
- Each AMT tunnel serves as a count for each EU and is also able to track data usage (bytes) delivered to the EU.

Disadvantages of this configuration:

- Additional devices (AMT gateway and relay pairs) are introduced into the transport path.
- Assuming multiple peering points between the domains, the EU gateway needs to be able to find the "correct" AMT relay in AD-1.

Architectural guidelines for this configuration are as follows:

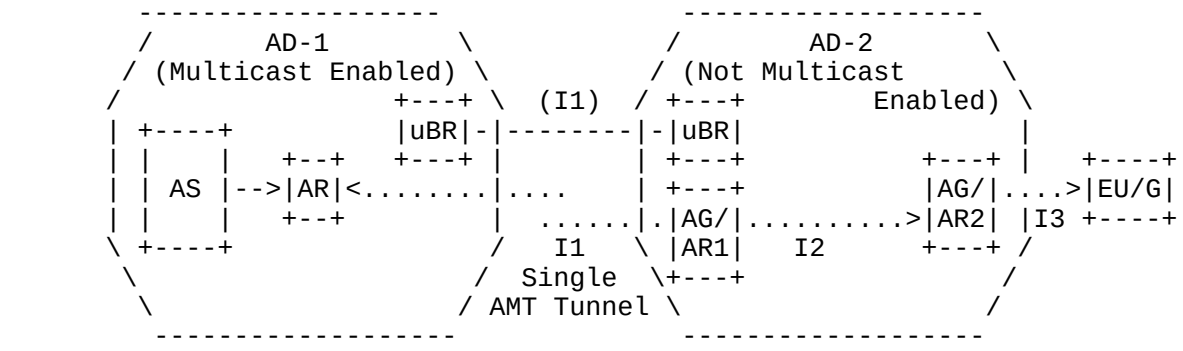
Guidelines (a) through (c) are the same as those described in Use Case 3.1. In addition,

d. It is necessary that proper procedures be implemented such that the AMT gateway at the EU device is able to find the correct AMT relay for each (S,G) content stream. Standard mechanisms for that selection are still subject to ongoing work. This includes the use of anycast gateway addresses, anycast DNS names, or explicit configuration that maps (S,G) to a relay address; or letting the application in the EU/G provide the relay address to the embedded AMT gateway function.

e. The AMT tunnel’s capabilities are expected to be sufficient for the purpose of collecting relevant information on the multicast streams delivered to EUs in AD-2.

3.5. AD-2 Not Multicast Enabled - Multiple AMT Tunnels through AD-2

Figure 5 illustrates a variation of Use Case 3.4:



uBR = unicast Border Router - not multicast enabled;
also, either AR = uBR (AD-1) or uBR = AGAR1 (AD-2)
AS = multicast (e.g., content) Application Source
AR = AMT Relay in AD-1
AGAR1 = AMT Gateway/Relay node in AD-2 across peering point
I1 = AMT tunnel connecting AR in AD-1 to gateway in AGAR1 in AD-2
AGAR2 = AMT Gateway/Relay node at AD-2 network edge
I2 = AMT tunnel connecting relay in AGAR1 to gateway in AGAR2
EU/G = Gateway client embedded in EU device
I3 = AMT tunnel connecting EU/G to AR in AGAR2

Figure 5: AMT Tunnel Connecting AMT Gateways and Relays

Use Case 3.4 results in several long AMT tunnels crossing the entire network of AD-2 linking the EU device and the AMT relay in AD-1 through the peering point. Depending on the number of EUs, there is a likelihood of an unacceptably high amount of traffic due to the large number of AMT tunnels -- and unicast streams -- through the peering point. This situation can be alleviated as follows:

- Provisioning of strategically located AMT nodes in AD-2. An AMT node comprises co-location of an AMT gateway and an AMT relay. No change is required by AD-1, as compared to Use Case 3.4. This can be done whenever AD-2 sees fit (e.g., too much traffic across the peering point).

- One such node is on the AD-2 side of the peering point (AMT node AGAR1 in Figure 5).

- A single AMT tunnel established across the peering point linking the AMT relay in AD-1 to the AMT gateway in AMT node AGAR1 in AD-2.

- AMT tunnels linking AMT node AGAR1 at the peering point in AD-2 to other AMT nodes located at the edges of AD-2: e.g., AMT tunnel I2 linking the AMT relay in AGAR1 to the AMT gateway in AMT node AGAR2 (Figure 5).

- AMT tunnels linking an EU device (via a gateway client embedded in the device) and an AMT relay in an appropriate AMT node at the edge of AD-2: e.g., I3 linking the EU gateway in the device to the AMT relay in AMT node AGAR2.

- In the simplest option (not shown), AD-2 only deploys a single AGAR1 node and lets the EU/G build AMT tunnels directly to it. This setup already solves the problem of replicated traffic across the peering point. As soon as there is a need to support more AMT tunnels to the EU/G, then additional AGAR2 nodes can be deployed by AD-2.

The advantage of such a chained set of AMT tunnels is that the total number of unicast streams across AD-2 is significantly reduced, thus freeing up bandwidth. Additionally, there will be a single unicast stream across the peering point instead of, possibly, an unacceptably large number of such streams per Use Case 3.4. However, this implies that several AMT tunnels will need to be dynamically configured by the various AMT gateways, based solely on the (S,G) information received from the application client at the EU device. A suitable mechanism for such dynamic configurations is therefore critical.

Architectural guidelines for this configuration are as follows:

Guidelines (a) through (c) are the same as those described in Use Case 3.1. In addition,

d. It is necessary that proper procedures be implemented such that the various AMT gateways (at the EU devices and the AMT nodes in AD-2) are able to find the correct AMT relay in other AMT nodes as appropriate. Standard mechanisms for that selection are still subject to ongoing work. This includes the use of anycast gateway addresses, anycast DNS names, or explicit configuration that maps (S,G) to a relay address. On the EU/G, this mapping information may come from the application.

e. The AMT tunnel’s capabilities are expected to be sufficient for the purpose of collecting relevant information on the multicast streams delivered to EUs in AD-2.

4. Functional Guidelines

Supporting functions and related interfaces over the peering point that enable the multicast transport of the application are listed in this section. Critical information parameters that need to be exchanged in support of these functions are enumerated, along with guidelines as appropriate. Specific interface functions for consideration are as follows.

4.1. Network Interconnection Transport Guidelines

The term "network interconnection transport" refers to the interconnection points between the two administrative domains. The following is a representative set of attributes that the two administrative domains will need to agree on to support multicast delivery.

- Number of peering points.
- Peering point addresses and locations.
- Connection type - Dedicated for multicast delivery or shared with other services.
- Connection mode - Direct connectivity between the two ADs or via another ISP.
- Peering point protocol support - Multicast protocols that will be used for multicast delivery will need to be supported at these points. Examples of such protocols include External BGP (EBGP) [RFC4760] peering via MP-BGP (Multiprotocol BGP) SAFI-2 [RFC4760].
- Bandwidth allocation - If shared with other services, then there needs to be a determination of the share of bandwidth reserved for multicast delivery. See Section 4.1.1 below for more details.
- QoS requirements - Delay and/or latency specifications that need to be specified in an SLA.
- AD roles and responsibilities - The role played by each AD for provisioning and maintaining the set of peering points to support multicast delivery.

4.1.1. Bandwidth Management

Like IP unicast traffic, IP multicast traffic carried across non-controlled networks must comply with congestion control principles as described in [BCP41] and as explained in detail for UDP IP multicast in [BCP145].

Non-controlled networks (such as the Internet) are networks where there is no policy for managing bandwidth other than best effort with a fair share of bandwidth under congestion. As a simplified rule of thumb, complying with congestion control principles means reducing bandwidth under congestion in a way that is fair to competing (typically TCP) flows ("rate adaptive").

In many instances, multicast content delivery evolves from intra-domain deployments where it is handled as a controlled network service and does not comply with congestion control principles. It was given a reserved amount of bandwidth and admitted to the network so that congestion never occurs. Therefore, the congestion control issue should be given specific attention when evolving to an inter-domain peering deployment.

In the case where end-to-end IP multicast traffic passes across the network of two ADs (and their subsidiaries/customers), both ADs must agree on a consistent traffic-management policy. If, for example, AD-1 sources non-congestion-aware IP multicast traffic and AD-2 carries it as best-effort traffic across links shared with other Internet traffic (subject to congestion), this will not work: under congestion, some amount of that traffic will be dropped, often rendering the remaining packets as undecodable garbage clogging up the network in AD-2; because this traffic is not congestion aware, the loss does not reduce this rate. Competing traffic will not get their fair share under congestion, and EUs will be frustrated by the extremely bad quality of both their IP multicast traffic and other (e.g., TCP) traffic. Note that this is not an IP multicast technology issue but is solely a transport-layer / application-layer issue: the problem would just as likely happen if AD-1 were to send non-rate-adaptive unicast traffic -- for example, legacy IPTV video-on-demand traffic, which is typically also non-congestion aware. Note that because rate adaptation in IP unicast video is commonplace today due to the availability of ABR (Adaptive Bitrate) video, it is very unlikely that this will happen in reality with IP unicast.

While the rules for traffic management apply whether IP multicast is tunneled or not, the one feature that can make AMT tunnels more difficult is the unpredictability of bandwidth requirements across underlying links because of the way they can be used: with native IP

multicast or GRE tunnels, the amount of bandwidth depends on the amount of content -- not the number of EUs -- and is therefore easier to plan for. AMT tunnels terminating in the EU/G, on the other hand, scale with the number of EUs. In the vicinity of the AMT relay, they can introduce a very large amount of replicated traffic, and it is not always feasible to provision enough bandwidth for all possible EUs to get the highest quality for all their content during peak utilization in such setups -- unless the AMT relays are very close to the EU edge. Therefore, it is also recommended that IP multicast rate adaptation be used, even inside controlled networks, when using AMT tunnels directly to the EU/G.

Note that rate-adaptive IP multicast traffic in general does not mean that the sender is reducing the bitrate but rather that the EUs that experience congestion are joining to a lower-bitrate (S,G) stream of the content, similar to ABR streaming over TCP. Therefore, migration from a non-rate-adaptive bitrate to a rate-adaptive bitrate in IP multicast will also change the dynamic (S,G) join behavior in the network, resulting in potentially higher performance requirements for IP multicast protocols (IGMP/PIM), especially on the last hops where dynamic changes occur (including AMT gateways/relays): in non-rate-adaptive IP multicast, only "channel change" causes state change, but in rate-adaptive multicast, congestion also causes state change.

Even though not fully specified in this document, peerings that rely on GRE/AMT tunnels may be across one or more transit ADs instead of an exclusive (non-shared, L1/L2) path. Unless those transit ADs are explicitly contracted to provide other than "best effort" transit for the tunneled traffic, the tunneled IP multicast traffic must be rate adaptive in order to not violate BCP 41 across those transit ADs.

4.2. Routing Aspects and Related Guidelines

The main objective for multicast delivery routing is to ensure that the EU receives the multicast stream from the "most optimal" source [INF_ATIS_10], which typically:

- Maximizes the multicast portion of the transport and minimizes any unicast portion of the delivery, and
- Minimizes the overall combined route distance of the network(s).

This routing objective applies to both native multicast and AMT; the actual methodology of the solution will be different for each. Regardless, the routing solution is expected to:

- Be scalable,
- Avoid or minimize new protocol development or modifications, and
- Be robust enough to achieve high reliability and to automatically adjust to changes and problems in the multicast infrastructure.

For both native and AMT environments, having a source as close as possible to the EU network is most desirable; therefore, in some cases, an AD may prefer to have multiple sources near different peering points. However, that is entirely an implementation issue.

4.2.1. Native Multicast Routing Aspects

Native multicast simply requires that the administrative domains coordinate and advertise the correct source address(es) at their network interconnection peering points (i.e., BRs). An example of multicast delivery via a native multicast process across two administrative domains is as follows, assuming that the interconnecting peering points are also multicast enabled:

- Appropriate information is obtained by the EU client, who is a subscriber to AD-2 (see Use Case 3.1). This information is in the form of metadata, and it contains instructions directing the EU client to launch an appropriate application if necessary, as well as additional information for the application about the source location and the group (or stream) ID in the form of (S,G) data. The "S" portion provides the name or IP address of the source of the multicast stream. The metadata may also contain alternate delivery information, such as specifying the unicast address of the stream.
- The client uses the join message with (S,G) to join the multicast stream [RFC4604]. To facilitate this process, the two ADs need to do the following:
  - Advertise the source ID(s) over the peering points.
  - Exchange such relevant peering point information as capacity and utilization.
  - Implement compatible multicast protocols to ensure proper multicast delivery across the peering points.

4.2.2. GRE Tunnel over Interconnecting Peering Point

If the interconnecting peering point is not multicast enabled and both ADs are multicast enabled, then a simple solution is to provision a GRE tunnel between the two ADs; see Use Case 3.2 (Section 3.2). The termination points of the tunnel will usually be a network engineering decision but generally will be between the BRs or even between the AD-2 BR and the AD-1 source (or source access router). The GRE tunnel would allow end-to-end native multicast or AMT multicast to traverse the interface. Coordination and advertisement of the source IP are still required.

The two ADs need to follow the same process as the process described in Section 4.2.1 to facilitate multicast delivery across the peering points.

4.2.3. Routing Aspects with AMT Tunnels

Unlike native multicast (with or without GRE), an AMT multicast environment is more complex. It presents a two-layered problem in that there are two criteria that should be simultaneously met:

- Find the closest AMT relay to the EU that also has multicast connectivity to the content source, and
- Minimize the AMT unicast tunnel distance.

There are essentially two components in the AMT specification:

AMT relays: These serve the purpose of tunneling UDP multicast traffic to the receivers (i.e., endpoints). The AMT relay will receive the traffic natively from the multicast media source and will replicate the stream on behalf of the downstream AMT gateways, encapsulating the multicast packets into unicast packets and sending them over the tunnel toward the AMT gateways. In addition, the AMT relay may collect various usage and activity statistics. This results in moving the replication point closer to the EU and cuts down on traffic across the network. Thus, the linear costs of adding unicast subscribers can be avoided. However, unicast replication is still required for each requesting endpoint within the unicast-only network.

AMT gateway: The gateway will reside on an endpoint; this could be any type of IP host, such as a Personal Computer (PC), mobile phone, Set-Top Box (STB), or appliances. The AMT gateway receives join and leave requests from the application via an Application Programming Interface (API). In this manner, the gateway allows the endpoint to conduct itself as a true multicast endpoint. The

AMT gateway will encapsulate AMT messages into UDP packets and send them through a tunnel (across the unicast-only infrastructure) to the AMT relay.

The simplest AMT use case (Section 3.3) involves peering points that are not multicast enabled between two multicast-enabled ADs. An AMT tunnel is deployed between an AMT relay on the AD-1 side of the peering point and an AMT gateway on the AD-2 side of the peering point. One advantage of this arrangement is that the tunnel is established on an as-needed basis and need not be a provisioned element. The two ADs can coordinate and advertise special AMT relay anycast addresses with, and to, each other. Alternately, they may decide to simply provision relay addresses, though this would not be an optimal solution in terms of scalability.

Use Cases 3.4 and 3.5 describe AMT situations that are more complicated, as AD-2 is not multicast enabled in these two cases. For these cases, the EU device needs to be able to set up an AMT tunnel in the most optimal manner. There are many methods by which relay selection can be done, including the use of DNS-based queries and static lookup tables [RFC7450]. The choice of the method is implementation dependent and is up to the network operators. Comparison of various methods is out of scope for this document and is left for further study.

An illustrative example of a relay selection based on DNS queries as part of an anycast IP address process is described here for Use Cases 3.4 and 3.5 (Sections 3.4 and 3.5). Using an anycast IP address for AMT relays allows all AMT gateways to find the "closest" AMT relay -- the nearest edge of the multicast topology of the source. Note that this is strictly illustrative; the choice of the method is up to the network operators. The basic process is as follows:

- Appropriate metadata is obtained by the EU client application. The metadata contains instructions directing the EU client to an ordered list of particular destinations to seek the requested stream and, for multicast, specifies the source location and the group (or stream) ID in the form of (S,G) data. The "S" portion provides the URI (name or IP address) of the source of the multicast stream, and the "G" identifies the particular stream originated by that source. The metadata may also contain alternate delivery information such as the address of the unicast form of the content to be used -- for example, if the multicast stream becomes unavailable.

- Using the information from the metadata and, possibly, information provisioned directly in the EU client, a DNS query is initiated in order to connect the EU client / AMT gateway to an AMT relay.

- Query results are obtained and may return an anycast address or a specific unicast address of a relay. Multiple relays will typically exist. The anycast address is a routable "pseudo-address" shared among the relays that can gain multicast access to the source.

- If a specific IP address unique to a relay was not obtained, the AMT gateway then sends a message (e.g., the discovery message) to the anycast address such that the network is making the routing choice of a particular relay, e.g., the relay that is closest to the EU. Details are outside the scope of this document. See [RFC4786].

- The contacted AMT relay then returns its specific unicast IP address (after which the anycast address is no longer required). Variations may exist as well.

- The AMT gateway uses that unicast IP address to initiate a three-way handshake with the AMT relay.

- The AMT gateway provides the (S,G) information to the AMT relay (embedded in AMT protocol messages).

- The AMT relay receives the (S,G) information and uses it to join the appropriate multicast stream, if it has not already subscribed to that stream.

- The AMT relay encapsulates the multicast stream into the tunnel between the relay and the gateway, providing the requested content to the EU.

4.2.4. Public Peering Routing Aspects

Figure 6 shows an example of a broadcast peering point.

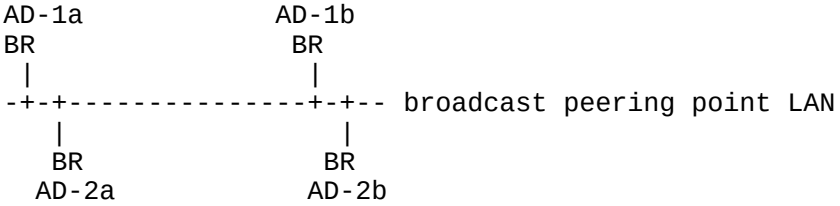


Figure 6: Broadcast Peering Point

A broadcast peering point is an L2 subnet connecting three or more ADs. It is common in IXPs and usually consists of Ethernet switch(es) operated by the IXP connecting to BRs operated by the ADs.

In an example setup domain, AD-2a peers with AD-1a and wants to receive IP multicast from it. Likewise, AD-2b peers with AD-1b and wants to receive IP multicast from it.

Assume that one or more IP multicast (S,G) traffic streams can be served by both AD-1a and AD-1b -- for example, because both AD-1a and AD-1b contact this content from the same content source.

In this case, AD-2a and AD-2b can no longer control which upstream domain -- AD-1a or AD-1b -- will forward this (S,G) into the LAN. The AD-2a BR requests the (S,G) from the AD-1a BR, and the AD-2b BR requests the same (S,G) from the AD-1b BR. To avoid duplicate packets, an (S,G) can be forwarded by only one router onto the LAN; PIM-SM / PIM-SSM detects requests for duplicate transmissions and resolves them via the so-called "assert" protocol operation, which results in only one BR forwarding the traffic. Assume that this is the AD-1a BR. AD-2b will then receive unexpected multicast traffic from a provider with whom it does not have a mutual agreement for that traffic. Quality issues in EUs behind AD-2b caused by AD-1a will cause a lot of issues related to responsibility and troubleshooting.

In light of these technical issues, we describe, via the following options, how IP multicast can be carried across broadcast peering point LANs:

1. IP multicast is tunneled across the LAN. Any of the GRE/AMT tunneling solutions mentioned in this document are applicable. This is the one case where a GRE tunnel between the upstream BR (e.g., AD-1a) and downstream BR (e.g., AD-2a) is specifically recommended, as opposed to tunneling across uBRs (which are not the actual BRs).

2. The LAN has only one upstream AD that is sourcing IP multicast, and native IP multicast is used. This is an efficient way to distribute the same IP multicast content to multiple downstream ADs. Misbehaving downstream BRs can still disrupt the delivery of IP multicast from the upstream BR to other downstream BRs; therefore, strict rules must be followed to prohibit such a case. The downstream BRs must ensure that they will always consider only the upstream BR as a source for multicast traffic: e.g., no BGP SAFI-2 peerings between the downstream ADs across the peering point LAN, so that the upstream BR is the only possible next hop reachable across this LAN. Also, routing policies can be

configured to avoid falling back to using SAFI-1 (unicast) routes for IP multicast if unicast BGP peering is not limited in the same way.

3. The LAN has multiple upstream ADs, but they are federated and agree on a consistent policy for IP multicast traffic across the LAN. One policy is that each possible source is only announced by one upstream BR. Another policy is that sources are redundantly announced (the problematic case mentioned in the example in Figure 6 above), but the upstream domains also provide mutual operational insight to help with troubleshooting (outside the scope of this document).

4.3. Back-Office Functions - Provisioning and Logging Guidelines

"Back office" refers to the following:

- Servers and content-management systems that support the delivery of applications via multicast and interactions between ADs.
- Functionality associated with logging, reporting, ordering, provisioning, maintenance, service assurance, settlement, etc.

4.3.1. Provisioning Guidelines

Resources for basic connectivity between ADs' providers need to be provisioned as follows:

- Sufficient capacity must be provisioned to support multicast-based delivery across ADs.
- Sufficient capacity must be provisioned for connectivity between all supporting back offices of the ADs as appropriate. This includes activating proper security treatment for these back-office connections (gateways, firewalls, etc.) as appropriate.

Provisioning aspects related to multicast-based inter-domain delivery are as follows.

The ability to receive a requested application via multicast is triggered via receipt of the necessary metadata. Hence, this metadata must be provided to the EU regarding the multicast URL -- and unicast fallback if applicable. AD-2 must enable the delivery of this metadata to the EU and provision appropriate resources for this purpose.

It is assumed that native multicast functionality is available across many ISP backbones, peering points, and access networks. If, however, native multicast is not an option (Use Cases 3.4 and 3.5), then:

- The EU must have a multicast client to use AMT multicast obtained from either (1) the application source (per agreement with AD-1) or (2) AD-1 or AD-2 (if delegated by the application source).

- If provided by AD-1 or AD-2, then the EU could be redirected to a client download site. (Note: This could be an application source site.) If provided by the application source, then this source would have to coordinate with AD-1 to ensure that the proper client is provided (assuming multiple possible clients).

- Where AMT gateways support different application sets, all AD-2 AMT relays need to be provisioned with all source and group addresses for streams it is allowed to join.

- DNS across each AD must be provisioned to enable a client gateway to locate the optimal AMT relay (i.e., longest multicast path and shortest unicast tunnel) with connectivity to the content's multicast source.

Provisioning aspects related to operations and customer care are as follows.

It is assumed that each AD provider will provision operations and customer care access to their own systems.

AD-1's operations and customer care functions must be able to see enough of what is happening in AD-2's network or in the service provided by AD-2 to verify their mutual goals and operations, e.g., to know how the EUs are being served. This can be done in two ways:

- Automated interfaces are built between AD-1 and AD-2 such that operations and customer care continue using their own systems. This requires coordination between the two ADs, with appropriate provisioning of necessary resources.

- AD-1's operations and customer care personnel are provided direct access to AD-2's systems. In this scenario, additional provisioning in these systems will be needed to provide necessary access. The two ADs must agree on additional provisioning to support this option.

4.3.2. Inter-domain Authentication Guidelines

All interactions between pairs of ADs can be discovered and/or associated with the account(s) utilized for delivered applications. Supporting guidelines are as follows:

- A unique identifier is recommended to designate each master account.
- AD-2 is expected to set up "accounts" (a logical facility generally protected by credentials such as login passwords) for use by AD-1. Multiple accounts, and multiple types or partitions of accounts, can apply, e.g., customer accounts, security accounts.

The reason to specifically mention the need for AD-1 to initiate interactions with AD-2 (and use some account for that), as opposed to the opposite, is based on the recommended workflow initiated by customers (see Section 4.4): the customer contacts the content source, which is part of AD-1. Consequently, if AD-1 sees the need to escalate the issue to AD-2, it will interact with AD-2 using the aforementioned guidelines.

4.3.3. Log-Management Guidelines

Successful delivery (in terms of user experience) of applications or content via multicast between pairs of interconnecting ADs can be improved through the ability to exchange appropriate logs for various workflows -- troubleshooting, accounting and billing, optimization of traffic and content transmission, optimization of content and application development, and so on.

Specifically, AD-1 take over primary responsibility for customer experience on behalf of the content source, with support from AD-2 as needed. The application/content owner is the only participant who has, and needs, full insight into the application level and can map the customer application experience to the network traffic flows -- which, with the help of AD-2 or logs from AD-2, it can then analyze and interpret.

The main difference between unicast delivery and multicast delivery is that the content source can infer a lot more about downstream network problems from a unicast stream than from a multicast stream: the multicast stream is not per EU, except after the last replication, which is in most cases not in AD-1. Logs from the application, including the receiver side at the EU, can provide insight but cannot help to fully isolate network problems because of

the IP multicast per-application operational state built across AD-1 and AD-2 (aka the (S,G) state and any other operational-state features, such as Diffserv QoS).

See Section 7 for more discussion regarding the privacy considerations of the model described here.

Different types of logs are known to help support operations in AD-1 when provided by AD-2. This could be done as part of AD-1/AD-2 contracts. Note that except for implied multicast-specific elements, the options listed here are not unique or novel for IP multicast, but they are more important for services novel to the operators than for operationally well-established services (such as unicast). We therefore detail them as follows:

- Usage information logs at an aggregate level.
- Usage failure instances at an aggregate level.
- Grouped or sequenced application access: performance, behavior, and failure at an aggregate level to support potential application-provider-driven strategies. Examples of aggregate levels include grouped video clips, web pages, and software-download sets.
- Security logs, aggregated or summarized according to agreement (with additional detail potentially provided during security events, by agreement).
- Access logs (EU), when needed for troubleshooting.
- Application logs ("What is the application doing?"), when needed for shared troubleshooting.
- Syslogs (network management), when needed for shared troubleshooting.

The two ADs may supply additional security logs to each other, as agreed upon in contract(s). Examples include the following:

- Information related to general security-relevant activity, which may be of use from a protection or response perspective: types and counts of attacks detected, related source information, related target information, etc.
- Aggregated or summarized logs according to agreement (with additional detail potentially provided during security events, by agreement).

4.4. Operations - Service Performance and Monitoring Guidelines

"Service performance" refers to monitoring metrics related to multicast delivery via probes. The focus is on the service provided by AD-2 to AD-1 on behalf of all multicast application sources (metrics may be specified for SLA use or otherwise). Associated guidelines are as follows:

- Both ADs are expected to monitor, collect, and analyze service performance metrics for multicast applications. AD-2 provides relevant performance information to AD-1; this enables AD-1 to create an end-to-end performance view on behalf of the multicast application source.

- Both ADs are expected to agree on the types of probes to be used to monitor multicast delivery performance. For example, AD-2 may permit AD-1’s probes to be utilized in the AD-2 multicast service footprint. Alternately, AD-2 may deploy its own probes and relay performance information back to AD-1.

"Service monitoring" generally refers to a service (as a whole) provided on behalf of a particular multicast application source provider. It thus involves complaints from EUs when service problems occur. EUs direct their complaints to the source provider; the source provider in turn submits these complaints to AD-1. The responsibility for service delivery lies with AD-1; as such, AD-1 will need to determine where the service problem is occurring -- in its own network or in AD-2. It is expected that each AD will have tools to monitor multicast service status in its own network.

- Both ADs will determine how best to deploy multicast service monitoring tools. Typically, each AD will deploy its own set of monitoring tools, in which case both ADs are expected to inform each other when multicast delivery problems are detected.

- AD-2 may experience some problems in its network. For example, for the AMT use cases (Sections 3.3, 3.4, and 3.5), one or more AMT relays may be experiencing difficulties. AD-2 may be able to fix the problem by rerouting the multicast streams via alternate AMT relays. If the fix is not successful and multicast service delivery degrades, then AD-2 needs to report the issue to AD-1.

- When a problem notification is received from a multicast application source, AD-1 determines whether the cause of the problem is within its own network or within AD-2. If the cause is within AD-2, then AD-1 supplies all necessary information to AD-2. Examples of supporting information include the following:
  - Kind(s) of problem(s).
  - Starting point and duration of problem(s).
  - Conditions in which one or more problems occur.
  - IP address blocks of affected users.
  - ISPs of affected users.
  - Type of access, e.g., mobile versus desktop.
  - Network locations of affected EUs.
- Both ADs conduct some form of root-cause analysis for multicast service delivery problems. Examples of various factors for consideration include:
  - Verification that the service configuration matches the product features.
  - Correlation and consolidation of the various customer problems and resource troubles into a single root-service problem.
  - Prioritization of currently open service problems, giving consideration to problem impacts, SLAs, etc.
  - Conducting service tests, including tests performed once or a series of tests over a period of time.
  - Analysis of test results.
  - Analysis of relevant network fault or performance data.
  - Analysis of the problem information provided by the customer.
- Once the cause of the problem has been determined and the problem has been fixed, both ADs need to work jointly to verify and validate the success of the fix.

4.5. Client Reliability Models / Service Assurance Guidelines

There are multiple options for instituting reliability architectures. Most are at the application level. Both ADs should work these options out per their contract or agreement and also with the multicast application source providers.

Network reliability can also be enhanced by the two ADs if they provision alternate delivery mechanisms via unicast means.

4.6. Application Accounting Guidelines

Application-level accounting needs to be handled differently in the application than in IP unicast, because the source side does not directly deliver packets to individual receivers. Instead, this needs to be signaled back by the receiver to the source.

For network transport diagnostics, AD-1 and AD-2 should have mechanisms in place to ensure proper accounting for the volume of bytes delivered through the peering point and, separately, the number of bytes delivered to EUs.

5. Troubleshooting and Diagnostics

Any service provider supporting multicast delivery of content should be able to collect diagnostics as part of multicast troubleshooting practices and resolve network issues accordingly. Issues may become apparent or identifiable through either (1) network monitoring functions or (2) problems reported by customers, as described in Section 4.4.

It is recommended that multicast diagnostics be performed, leveraging established operational practices such as those documented in [MDH-05]. However, given that inter-domain multicast creates a significant interdependence of proper networking functionality between providers, there exists a need for providers to be able to signal (or otherwise alert) each other if there are any issues noted by either one.

For troubleshooting purposes, service providers may also wish to allow limited read-only administrative access to their routers to their AD peers. Access to active troubleshooting tools -- especially [Traceroute] and the tools discussed in [Mtrace-v2] -- is of specific interest.

Another option is to include this functionality in the IP multicast receiver application on the EU device and allow these diagnostics to be remotely used by support operations. Note, though, that AMT does not allow the passing of traceroute or mtrace requests; therefore, troubleshooting in the presence of AMT does not work as well end to end as it can with native (or even GRE-encapsulated) IP multicast, especially with regard to traceroute and mtrace. Instead, troubleshooting directly on the actual network devices is then more likely necessary.

The specifics of notifications and alerts are beyond the scope of this document, but general guidelines are similar to those described in Section 4.4. Some general communications issues are as follows.

- Appropriate communications channels will be established between the customer service and operations groups from both ADs to facilitate information-sharing related to diagnostic troubleshooting.

- A default resolution period may be considered to resolve open issues. Alternately, mutually acceptable resolution periods could be established, depending on the severity of the identified trouble.

6. Security Considerations

6.1. DoS Attacks (against State and Bandwidth)

Reliable IP multicast operations require some basic protection against DoS (Denial of Service) attacks.

SSM IP multicast is self-protecting against attacks from illicit sources; such traffic will not be forwarded beyond the first-hop router, because that would require (S,G) membership reports from the receiver. Only valid traffic from sources will be forwarded, because RPF ("Reverse Path Forwarding") is part of the protocols. One can say that protection against spoofed source traffic performed in the style of [BCP38] is therefore built into PIM-SM / PIM-SSM.

Receivers can attack SSM IP multicast by originating such (S,G) membership reports. This can result in a DoS attack against state through the creation of a large number of (S,G) states that create high control-plane load or even inhibit the later creation of a valid (S,G). In conjunction with collaborating illicit sources, it can also result in the forwarding of traffic from illicit sources.

Today, these types of attacks are usually mitigated by explicitly defining the set of permissible (S,G) on, for example, the last-hop routers in replicating IP multicast to EUs (e.g., via (S,G) access control lists applied to IGMP/MLD membership state creation). Each AD (say, "ADi") is expected to know what sources located in ADi are permitted to send and what their valid (S,G)s are. ADi can therefore also filter invalid (S,G)s for any "S" located inside ADi, but not sources located in another AD.

In the peering case, without further information, AD-2 is not aware of the set of valid (S,G) from AD-1, so this set needs to be communicated via operational procedures from AD-1 to AD-2 to provide protection against this type of DoS attack. Future work could signal this information in an automated way: BGP extensions, DNS resource records, or backend automation between AD-1 and AD-2. Backend automation is, in the short term, the most viable solution: unlike BGP extensions or DNS resource records, backend automation does not require router software extensions. Observation of traffic flowing via (S,G) state could also be used to automate the recognition of invalid (S,G) state created by receivers in the absence of explicit information from AD-1.

The second type of DoS attack through (S,G) membership reports exists when the attacking receiver creates too much valid (S,G) state and the traffic carried by these (S,G)s congests bandwidth on links shared with other EUs. Consider the uplink to a last-hop router connecting to 100 EUs. If one EU joins to more multicast content than what fits into this link, then this would also impact the quality of the same content for the other 99 EUs. If traffic is not rate adaptive, the effects are even worse.

The mitigation technique is the same as what is often employed for unicast: policing of the per-EU total amount of traffic. Unlike unicast, though, this cannot be done anywhere along the path (e.g., on an arbitrary bottleneck link); it has to happen at the point of last replication to the different EU. Simple solutions such as limiting the maximum number of joined (S,G)s per EU are readily available; solutions that take consumed bandwidth into account are available as vendor-specific features in routers. Note that this is primarily a non-peering issue in AD-2; it only becomes a peering issue if the peering link itself is not big enough to carry all possible content from AD-1 or, as in Use Case 3.4, when the AMT relay in AD-1 is that last replication point.

Limiting the amount of (S,G) state per EU is also a good first measure to prohibit too much undesired "empty" state from being built (state not carrying traffic), but it would not suffice in the case of DDoS attacks, e.g., viruses that impact a large number of EU devices.

6.2. Content Security

Content confidentiality, DRM (Digital Rights Management), authentication, and authorization are optional, based on the content delivered. For content that is "FTA" (Free To Air), the following considerations can be ignored, and content can be sent unencrypted and without EU authentication and authorization. Note, though, that the mechanisms described here may also be desirable for the application source to better track users even if the content itself would not require it.

For inter-domain content, there are at least two models for content confidentiality, including (1) DRM authentication and authorization and (2) EU authentication and authorization:

- In the classical (IP)TV model, responsibility is per domain, and content is and can be passed on unencrypted. AD-1 delivers content to AD-2; AD-2 can further process the content, including features like ad insertion, and AD-2 is the sole point of contact regarding the contact for its EUs. In this document, we do not consider this case because it typically involves service aspects operated by AD-2 that are higher than the network layer; this document focuses on the network-layer AD-1/AD-2 peering case but not the application-layer peering case. Nevertheless, this model can be derived through additional work beyond what is described here.

- The other model is the one in which content confidentiality, DRM, EU authentication, and EU authorization are end to end: responsibilities of the multicast application source provider and receiver application. This is the model assumed here. It is also the model used in Internet "Over the Top" (OTT) video delivery. Below, we discuss the threats incurred in this model due to the use of IP multicast in AD-1 or AD-2 and across the peering point.

End-to-end encryption enables end-to-end EU authentication and authorization: the EU may be able to join (via IGMP/MLD) and receive the content, but it can only decrypt it when it receives the decryption key from the content source in AD-1. The key is the authorization. Keeping that key to itself and prohibiting playout of the decrypted content to non-copy-protected interfaces are typical DRM features in that receiver application or EU device operating system.

End-to-end encryption is continuously attacked. Keys may be subject to brute-force attacks so that content can potentially be decrypted later, or keys are extracted from the EU application/device and shared with other unauthenticated receivers. One important class of

content is where the value is in live consumption, such as sports or other event (e.g., concert) streaming. Extraction of keying material from compromised authenticated EUs and sharing with unauthenticated EUs are not sufficient. It is also necessary for those unauthenticated EUs to get a streaming copy of the content itself. In unicast streaming, they cannot get such a copy from the content source (because they cannot authenticate), and, because of asymmetric bandwidths, it is often impossible to get the content from compromised EUs to a large number of unauthenticated EUs. EUs behind classical "16 Mbps down, 1 Mbps up" ADSL links are the best example. With increasing broadband access speeds, unicast peer-to-peer copying of content becomes easier, but it likely will always be easily detectable by the ADs because of its traffic patterns and volume.

When IP multicast is being used without additional security, AD-2 is not aware of which EU is authenticated for which content. Any unauthenticated EU in AD-2 could therefore get a copy of the encrypted content without triggering suspicion on the part of AD-2 or AD-1 and then either (1) live-decode it, in the presence of the compromised authenticated EU and key-sharing or (2) decrypt it later, in the presence of federated brute-force key-cracking.

To mitigate this issue, the last replication point that is creating (S,G) copies to EUs would need to permit those copies only after authentication of the EUs. This would establish the same authenticated "EU only" copy that is used in unicast.

Schemes for per-EU IP multicast authentication/authorization (and, as a result, non-delivery or copying of per-content IP multicast traffic) have been built in the past and are deployed in service providers for intra-domain IPTV services, but no standards exist for this. For example, there is no standardized RADIUS attribute for authenticating the IGMP/MLD filter set, but such implementations exist. The authors of this document are specifically also not aware of schemes where the same authentication credentials used to get the encryption key from the content source could also be used to authenticate and authorize the network-layer IP multicast replication for the content. Such schemes are technically not difficult to build and would avoid creating and maintaining a separate network traffic-forwarding authentication/authorization scheme decoupled from the end-to-end authentication/authorization system of the application.

If delivery of such high-value content in conjunction with the peering described here is desired, the short-term recommendations are for sources to clearly isolate the source and group addresses used for different content bundles, communicate those (S,G) patterns from AD-1 to AD-2, and let AD-2 leverage existing per-EU authentication/ authorization mechanisms in network devices to establish filters for (S,G) sets to each EU.

6.3. Peering Encryption

Encryption at peering points for multicast delivery may be used per agreement between AD-1 and AD-2.

In the case of a private peering link, IP multicast does not have attack vectors on a peering link different from those of IP unicast, but the content owner may have defined strict constraints against unauthenticated copying of even the end-to-end encrypted content; in this case, AD-1 and AD-2 can agree on additional transport encryption across that peering link. In the case of a broadcast peering connection (e.g., IXP), transport encryption is again the easiest way to prohibit unauthenticated copies by other ADs on the same peering point.

If peering is across a tunnel that spans intermittent transit ADs (not discussed in detail in this document), then encryption of that tunnel traffic is recommended. It not only prohibits possible "leakage" of content but also protects the information regarding what content is being consumed in AD-2 (aggregated privacy protection).

See Section 6.4 for reasons why the peering point may also need to be encrypted for operational reasons.

6.4. Operational Aspects

Section 4.3.3 discusses the exchange of log information, and Section 7 discusses the exchange of program information. All these operational pieces of data should by default be exchanged via authenticated and encrypted peer-to-peer communication protocols between AD-1 and AD-2 so that only the intended recipients in the peers' AD have access to it. Even exposure of the least sensitive information to third parties opens up attack vectors. Putting valid (S,G) information, for example, into DNS (as opposed to passing it via secured channels from AD-1 to AD-2) to allow easier filtering of invalid (S,G) information would also allow attackers to more easily identify valid (S,G) information and change their attack vector.

From the perspective of the ADs, security is most critical for log information, as it provides operational insight into the originating AD but also contains sensitive user data.

Sensitive user data exported from AD-2 to AD-1 as part of logs could be as much as the equivalent of 5-tuple unicast traffic flow accounting (but not more, e.g., no application-level information). As mentioned in Section 7, in unicast, AD-1 could capture these traffic statistics itself because this is all about traffic flows (originated by AD-1) to EU receivers in AD-2, and operationally passing it from AD-2 to AD-1 may be necessary when IP multicast is used because of the replication taking place in AD-2.

Nevertheless, passing such traffic statistics inside AD-1 from a capturing router to a backend system is likely less subject to third-party attacks than passing it "inter-domain" from AD-2 to AD-1, so more diligence needs to be applied to secure it.

If any protocols used for the operational exchange of information are not easily secured at the transport layer or higher (because of the use of legacy products or protocols in the network), then AD-1 and AD-2 can also consider ensuring that all operational data exchanges go across the same peering point as the traffic and use network-layer encryption of the peering point (as discussed previously) to protect it.

End-to-end authentication and authorization of EUs may involve some kind of token authentication and are done at the application layer, independently of the two ADs. If there are problems related to the failure of token authentication when EUs are supported by AD-2, then some means of validating proper operation of the token authentication process (e.g., validating that backend servers querying the multicast application source provider’s token authentication server are communicating properly) should be considered. Implementation details are beyond the scope of this document.

In the event of a security breach, the two ADs are expected to have a mitigation plan for shutting down the peering point and directing multicast traffic over alternative peering points. It is also expected that appropriate information will be shared for the purpose of securing the identified breach.

7. Privacy Considerations

The described flow of information about content and EUs as described in this document aims to maintain privacy:

AD-1 is operating on behalf of (or owns) the content source and is therefore part of the content-consumption relationship with the EU. The privacy considerations between the EU and AD-1 are therefore generally the same (with one exception; see below) as they would be if no IP multicast was used, especially because end-to-end encryption can and should be used for any privacy-conscious content.

Information related to inter-domain multicast transport service is provided to AD-1 by the AD-2 operators. AD-2 is not required to gain additional insight into the user's behavior through this process other than what it would already have without service collaboration with AD-1, unless AD-1 and AD-2 agree on it and get approval from the EU.

For example, if it is deemed beneficial for the EU to get support directly from AD-2, then it would generally be necessary for AD-2 to be aware of the mapping between content and network (S,G) state so that AD-2 knows which (S,G) to troubleshoot when the EU complains about problems with specific content. The degree to which this dissemination is done by AD-1 explicitly to meet privacy expectations of EUs is typically easy to assess by AD-1. Two simple examples are as follows:

- For a sports content bundle, every EU will happily click on the "I approve that the content program information is shared with your service provider" button, to ensure best service reliability, because service-conscious AD-2 would likely also try to ensure that high-value content, such as the (S,G) for the Super Bowl, would be the first to receive care in the case of network issues.

- If the content in question was content for which the EU expected more privacy, the EU should prefer a content bundle that included this content in a large variety of other content, have all content end-to-end encrypted, and not share programming information with AD-2, to maximize privacy. Nevertheless, the privacy of the EU against AD-2 observing traffic would still be lower than in the equivalent setup using unicast, because in unicast, AD-2 could not correlate which EUs are watching the same content and use that to deduce the content. Note that even the setup in Section 3.4, where AD-2 is not involved in IP multicast at all, does not provide privacy against this level of analysis by AD-2, because there is no transport-layer encryption in AMT; therefore, AD-2 can correlate by on-path traffic analysis who is consuming the same

content from an AMT relay from both the (S,G) join messages in AMT and the identical content segments (that were replicated at the AMT relay).

In summary, because only content to be consumed by multiple EUs is carried via IP multicast here and all of that content can be end-to-end encrypted, the only privacy consideration specific to IP multicast is for AD-2 to know or reconstruct what content an EU is consuming. For content for which this is undesirable, some form of protections as explained above are possible, but ideally, the model described in Section 3.4 could be used in conjunction with future work, e.g., adding Datagram Transport Layer Security (DTLS) encryption [RFC6347] between the AMT relay and the EU.

Note that IP multicast by nature would permit the EU's privacy against the content source operator because, unlike unicast, the content source does not natively know which EU is consuming which content: in all cases where AD-2 provides replication, only AD-2 knows this directly. This document does not attempt to describe a model that maintains such a level of privacy against the content source; rather, we describe a model that only protects against exposure to intermediate parties -- in this case, AD-2.

8. IANA Considerations

This document does not require any IANA actions.

9. References

9.1. Normative References

[RFC2784] Farinacci, D., Li, T., Hanks, S., Meyer, D., and P. Traina, "Generic Routing Encapsulation (GRE)", RFC 2784, DOI 10.17487/RFC2784, March 2000, <https://www.rfc-editor.org/info/rfc2784>.

[RFC3376] Cain, B., Deering, S., Kouvelas, I., Fenner, B., and A. Thyagarajan, "Internet Group Management Protocol, Version 3", RFC 3376, DOI 10.17487/RFC3376, October 2002, <https://www.rfc-editor.org/info/rfc3376>.

[RFC3810] Vida, R., Ed., and L. Costa, Ed., "Multicast Listener Discovery Version 2 (MLDv2) for IPv6", RFC 3810, DOI 10.17487/RFC3810, June 2004, <https://www.rfc-editor.org/info/rfc3810>.

[RFC4760] Bates, T., Chandra, R., Katz, D., and Y. Rekhter, "Multiprotocol Extensions for BGP-4", RFC 4760, DOI 10.17487/RFC4760, January 2007, <https://www.rfc-editor.org/info/rfc4760>.

[RFC4604] Holbrook, H., Cain, B., and B. Haberman, "Using Internet Group Management Protocol Version 3 (IGMPv3) and Multicast Listener Discovery Protocol Version 2 (MLDv2) for Source-Specific Multicast", RFC 4604, DOI 10.17487/RFC4604, August 2006, <https://www.rfc-editor.org/info/rfc4604>.

[RFC4609] Savola, P., Lehtonen, R., and D. Meyer, "Protocol Independent Multicast - Sparse Mode (PIM-SM) Multicast Routing Security Issues and Enhancements", RFC 4609, DOI 10.17487/RFC4609, October 2006, <https://www.rfc-editor.org/info/rfc4609>.

[RFC7450] Bumgardner, G., "Automatic Multicast Tunneling", RFC 7450, DOI 10.17487/RFC7450, February 2015, <https://www.rfc-editor.org/info/rfc7450>.

[RFC7761] Fenner, B., Handley, M., Holbrook, H., Kouvelas, I., Parekh, R., Zhang, Z., and L. Zheng, "Protocol Independent Multicast - Sparse Mode (PIM-SM): Protocol Specification (Revised)", STD 83, RFC 7761, DOI 10.17487/RFC7761, March 2016, <https://www.rfc-editor.org/info/rfc7761>.

[BCP38] Ferguson, P. and D. Senie, "Network Ingress Filtering: Defeating Denial of Service Attacks which employ IP Source Address Spoofing", BCP 38, RFC 2827, May 2000, <https://www.rfc-editor.org/info/rfc2827>.

[BCP41] Floyd, S., "Congestion Control Principles", BCP 41, RFC 2914, September 2000, <https://www.rfc-editor.org/info/rfc2914>.

[BCP145] Eggert, L., Fairhurst, G., and G. Shepherd, "UDP Usage Guidelines", BCP 145, RFC 8085, March 2017, <https://www.rfc-editor.org/info/rfc8085>.

9.2. Informative References

[RFC4786] Abley, J. and K. Lindqvist, "Operation of Anycast Services", BCP 126, RFC 4786, DOI 10.17487/RFC4786, December 2006, <https://www.rfc-editor.org/info/rfc4786>.

[RFC6347] Rescorla, E. and N. Modadugu, "Datagram Transport Layer Security Version 1.2", RFC 6347, DOI 10.17487/RFC6347, January 2012, <https://www.rfc-editor.org/info/rfc6347>.

[INF_ATIS_10] "CDN Interconnection Use Cases and Requirements in a Multi-Party Federation Environment", ATIS Standard A-0200010, December 2012.

[MDH-05] Thaler, D. and B. Aboba, "Multicast Debugging Handbook", Work in Progress, draft-ietf-mboned-mdh-05, November 2000.

[Traceroute] "traceroute.org", <http://traceroute.org/#source%20code>.

[Mtrace-v2] Asaeda, H., Meyer, K., and W. Lee, Ed., "Mtrace Version 2: Traceroute Facility for IP Multicast", Work in Progress, draft-ietf-mboned-mtrace-v2-22, December 2017.

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