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Host Groups: A Multicast Extension to the Internet Protocol

1. Status of this Memo

This RFC defines a model of service for Internet multicasting and proposes an extension to the Internet Protocol (IP) to support such a multicast service. Discussion and suggestions for improvements are requested. Distribution of this memo is unlimited.

2. Acknowledgements

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The Internet task force on end-to-end protocols, headed by Bob Braden, has provided valuable input in the development of the host group model.

3. Introduction

In this paper, we describe a model of multicast service we call host groups and propose this model as a way to support multicast in the DARPA Internet environment [14]. We argue that it is feasible to implement this facility as an extension of the existing "unicast" IP datagram model and mechanism.

Multicast is the transmission of a datagram packet to a set of zero or more destination hosts in a network or internetwork, with a single address specifying the set of destination hosts. For example, hosts A, B, C and D may be associated with multicast address X. On transmission, a packet with destination address X is delivered with datagram reliability to hosts A, B, C and D.

Multicast has two primary uses, namely distributed binding and multi-destination delivery. As a binding mechanism, multicast is a robust and often more efficient alternative to the use of name servers for finding a particular object or service when a particular host address is not known. For example, in a distributed file system, all the file servers may be associated with one well-known multicast address. To bind a file name to a particular server, a client sends a query packet containing the file name to the file server multicast address, for delivery to all the file servers. The

server that recognizes the file name then responds to the client, allowing subsequent interaction directly with that server host. Even when name servers are employed, multicast can be used as the first step in the binding process, that is, finding a name server.

Multi-destination delivery is useful to several applications, including:

- distributed, replicated databases [6,9].

- conferencing [11].

- distributed parallel computation, including distributed gaming [2].

Ideally, multicast transmission to a set of hosts is not more complicated or expensive for the sender than transmission to a single host. Similarly, multicast transmission should not be more expensive for the networks and gateways than traversing the shortest path tree that connects the sending host to the hosts identified by the multicast address.

Multicast, transmission to a set of hosts, is properly distinguished from broadcast, transmission to all hosts on a network or internetwork. Broadcast is not a generally useful facility since there are few reasons for communicating with all hosts.

A variety of local network applications and systems make use of multicast. For instance, the V distributed system [8] uses network-level multicast for implementing efficient operations on groups of processes spanning multiple machines. Similar use is being made for replicated databases [6] and other distributed applications [4]. Providing multicast in the Internet environment would allow porting such local network distributed applications to the Internet, as well as making some existing Internet applications more robust and portable (by, for example, removing "wired-in" lists of addresses, such as gateway addresses).

At present, an Internet application logically requiring multicast must send individually addressed packets to each recipient. There are two problems with this approach. Firstly, requiring the sending host to know the specific addresses of all the recipients defeats its use as a binding mechanism. For example, a diskless workstation needs on boot to determine the network address of a disk server and it is undesirable to "wire in" specific network addresses. With a multicast facility, the multicast address of the boot servers (or

name servers that hold the addresses of the boot servers) can be well-known, allowing the workstation to transmit its initial queries to this address.

Secondly, transmitting multiple copies of the same packet makes inefficient use of network bandwidth, gateway resources and sender resources. For instance, the same packet may repeatedly traverse the same network links and pass through the same gateways. Furthermore, the local network level cannot recognize multi-destination delivery to take advantage of multicast facilities that the underlying network technologies may provide. For example, local-area bus, ring, or radio networks, as well as satellite-based wide-area networks, can provide efficient multicast delivery directly. Besides using excessive communication resources, the use of multiple transmissions to effect multicast severely limits the amount of parallelism in transmission and processing that can be achieved compared to an integrated multicast facility.

The next section describes the host group model of multicast service. Section 5 describes the extensions to IP to support the host group model. Section 6 discusses the implementation of multicast within the networks and gateways making up the Internet. Section 7 relates this model to other proposals. Finally, we conclude with remarks on our experimental prototype implementation of host groups and comments on future directions for investigation.

4. The Host Group Model

The Internet architecture defines a name space of individual host addresses. The host group model extends that name space to include addresses of host groups. A host group is a set of zero or more Internet hosts <1>. When an IP packet is sent with a host group address as its destination, it is delivered with "best effort" datagram reliability to all members of that host group.

The sender need not be a member of the destination group. We refer to such a group as open, in contrast to a closed group where only members are allowed to send to the group. We chose to provide open groups because they are more flexible and more consistent as an extension of conventional unicast models (even though they may harder to implement).

Dynamic management of group membership provides flexible binding of Internet addresses to hosts. Hosts may join and leave groups over time. A host may also belong to more than one group at a time. Finally, a host may belong to no groups at times, during which that host is unreachable within the Internet architecture. In fact, a

host need not have an individual Internet address at all. Some hosts may only be associated with multi-host group addresses. For instance, there may be no reason to contact an individual time server in the Internet, so time servers would not require individual addresses.

Internet addresses are dynamically allocated for transient groups, groups that often last only as long as the execution of a single distributed program. In addition, a range of host group identifiers is reserved for identifying permanent groups. One use of permanent host groups identifiers is for host groups with standard logical meanings such as "name server group", "boot server group", "Internet monitor group", etc.

In the current Internet architecture, addresses are bound to single hosts. The host group model generalizes the binding of Internet addresses to hosts by allowing one address to bind to multiple hosts on multiple networks, more than one address to be bound (in part) to one host, and the binding of an address to host to be dynamic, i.e. possible to be modified under application control. Within this more general model, the current architecture is supported as a special case, retaining its current semantics and implementation.

The following subsections provide further details of the model.

4.1. Host Group Management

Dynamic binding of Internet addresses to hosts is managed by the following three operations which are made available to clients of the Internet Protocol <2>:

CreateGroup (type) --> outcome, group-address, access-key

requests the creation of a new transient host group with the invoking host as its only member. The type argument specifies whether the group is restricted or unrestricted. A restricted group restricts membership based on the access-key. Only hosts presenting a valid host access-key are allowed to join. All unrestricted host groups have a null access-key. outcome indicates whether the request is approved or denied. If it is approved, a new transient group address is returned in group-address. access-key is the protection key (or password) associated with the new group. This should fail only if there are no free transient group addresses.

JoinGroup (group-address, access-key) --> outcome

requests that the invoking host become a member of the identified host group (permanent or transient). outcome indicates whether the request is approved or denied. A request is denied if the access key is invalid.

LeaveGroup (group-address) --> outcome

requests that the invoking host be dropped from membership in the identified group (permanent or transient). outcome indicates whether the request is approved or denied.

There is no operation to destroy a transient host group because a transient host group is deemed to no longer exist when its membership goes to zero.

Permanent host group addresses are allocated and published by Internet administrators, in the same way as well-known TCP and UDP port numbers. That is, they are published in future editions of the "Assigned Numbers" document [17].

4.2. Packet Transmission

Transmission of a packet in the host group model is controlled by two parameters of scope, one being the destination internetwork address and the other being the "distance" to the destination host(s). In particular,

Send (dest-address, source-address, data, distance)

transmits the specified data in an internetwork datagram to the host(s) identified by dest-address that are within the specified distance. The destination address is thus similar to conventional networks except that delivery may be to multiple hosts; the distance parameter requires further discussion.

Distance may be measured in several ways, including number of network hops, time to deliver and what might be called administrative distance. Administrative distance refers to the distance between the administrations of two different networks. For example, in a company the networks of the research group and advanced development group might be considered quite close to each other, networks of the corporate management more distant, and networks of other companies much more distant. One may wish to restrict a query to members within one’s own administrative domain because servers outside that domain may not be trusted. Similarly, error reporting outside of an administrative domain may not be productive and may in fact be confusing.

Besides limiting the scope of transmission, the distance parameter can be used to control the scope of multicast as a binding mechanism and to implement an expanding scope of search for a desired service. For instance, to locate a name server familiar with a given name, one might check with nearby name servers and expand the distance (by incrementing the distance on retransmission) to include more distant name servers until the name is found.

To reach all members of a group, a sender specifies the maximum value for the distance parameter. This maximum must exceed the "diameter" of the Internet.

Packet reception is the same as conventional architectures. That is,

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Receive () --> dest-address, source-address, data
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returns the next internetwork datagram that is, or has been, received.

4.3. Delivery Requirements

We identify several requirements for the packet delivery mechanism that are essential to host groups being a useful and used facility.

Firstly, given the predominance of broadcast local-area networks and the locality of communication to individual networks, the delivery mechanism must be able to exploit the hardware's capability for very efficient multicast within a single local-area network.

Secondly, the delivery mechanism must scale in sophistication to efficient delivery across the Internet as it acquires high-speed wide-area communication links and higher performance gateways. The former are being provided by the introduction of high-speed satellite channels and long-haul fiber optic links. The latter are made feasible by the falling cost of memory and processing power plus the increasing importance in controlling access to relatively unprotected local network environments. A host group delivery mechanism must be able to take advantage of these trends as they materialize.

Finally, the delivery mechanism must avoid "systematic errors" in delivery to members of the host group. That is, a small number of repeated transmissions must result in delivery to all group

members within the specified distance, unless a member is disconnected or has failed. We refer to this property as coverage. In general, most reliable protocols make this basic assumption for unicast delivery. It is important to guarantee this assumption for multicast as well or else applications using multicast may fail in unexpected ways when coverage is not provided. For efficiency, the multicast delivery mechanism should also avoid regularly delivering multiple copies of a packet to individual hosts.

Failure notification is not viewed as an essential requirement, given the datagram semantics of delivery. However, a host group extension to IP should provide "hint"-level failure notification as the natural extension of the failure notification for unicast.

5. Extensions to IP

This section discusses the specific extensions to the DARPA Internet Protocol required to support the host group model. The extensions need be implemented only on those hosts that wish to join host groups or send to host groups; existing implementations are not affected by the proposed changes.

5.1. Group Addresses

A portion of the 32-bit IP address space is reserved for host group addresses. The range of group addresses is chosen to be easily recognized and to not conflict with existing individual addresses. Either Class A addresses with a distinguished (currently unused) network number or Class D addresses (those starting with 111) would be suitable. The range of group addresses is further subdivided into a set of permanent group addresses and a set of temporary group addresses.

Host group addresses may be used in the same way as individual addresses in the source, destination, and options fields of IP datagrams. An IP implementation adds to the list of its own individual addresses, the addresses of all groups to which it belongs. The source addresses of locally originated datagrams are validated against the list, and incoming datagrams which are not destined to an address on the list are discarded. The addresses on the list change dynamically as IP users create, join and leave groups.

5.2. Group Management

To support the group management operations of CreateGroup, JoinGroup and LeaveGroup, an IP module must interact with one or more multicast agents which reside in neighbouring gateways or other special-purpose hosts. These interaction are handled by an Internet Group Management Protocol (IGMP) which, like ICMP [15], is an integral part of the IP implementation. A proposed specification for IGMP is given in Appendix I.

5.3. Multicast Delivery

In order to transmit a datagram destined to a host group, an IP module must map the destination group address into a local network address. As with individual IP addresses, the mapping algorithm is local-network- specific. On networks that directly support multicast, the IP host group address is mapped to a local network multicast address that includes all local members of the host group plus one or more multicast agents. For networks that do not directly support multicast, the mapping may be to a more general broadcast address, to a list of local unicast addresses, or perhaps to the address of a single machine that handles multi-destination relaying.

5.4. Distance Control

The existing Time to Live field in the IP header can be used for crude control over the delivery radius of multicast datagrams. To provide finer-grain control, a new IP option is defined to specify the maximum delivery distance in "administrative units", such as "this network", "this department", "this company", "this country", etc. The set of units and their encoding is to be determined.

6. Implementation

In this section, we sketch a design for implementing the host group model within the Internet. This description of the design is given to further support the feasibility of the host group model as well as point out some of the problems yet to be addressed.

Implementation of host groups involves implementing a binding mechanism (binding Internet addresses to zero or more hosts) and a packet delivery mechanism (delivering a packet to each host to which its destination address binds). This facility fits most naturally into the gateways of the Internet and the switching nodes of the constituent point-to-point networks (as opposed to separate machines) because multicast binding and delivery is a natural extension of the

unicast binding and delivery (i.e. routing plus store-and-forward). That is, a multicast packet is routed and transmitted to multiple destinations, rather than to a single destination.

In the following description, we start with a basic, simple implementation that provides coverage and then refine this mechanism with various optimizations to improve efficiency of delivery and group management.

6.1. Basic Implementation

A host group defines a network group, which is the set of networks containing current members of the host group. When a packet is sent to a host group, a copy is delivered to each network in the corresponding network group. Then, within each network, a copy is delivered to each host belonging to the group.

To support such multicast delivery, every Internet gateway maintains the following data structures:

- routing table: conventional Internet routing information, including the distance and direction to the nearest gateway on every network.

- network membership table: A set of records, one for every currently existing host group. The network membership record for a group lists the network group, i.e. the networks that contain members of the group.

- local host membership table: A set of records, one for each host group that has members on directly attached networks. Each local host membership record indicates the local hosts that are members of the associated host group. For networks that support multicast or broadcast, the record may contain only the local network-specific multicast address used by the group plus a count of local members. Otherwise, local group members may be identified by a list of unicast addresses to be used in the software implementation of multicast within the network.

A host invokes the multicast delivery service by sending a group-destined IP datagram to an immediate neighbour gateway (i.e. a gateway that is directly attached to the same network as the sending host). Upon receiving a group-destined datagram from a directly attached network, a gateway looks up the network membership record corresponding to the destination address of the datagram. For each of the networks listed in the membership

record, the gateway consults its routing table. If, according to the routing table, a member network is directly attached, the gateway transmits a copy of the datagram on that network, using the network-specific multicast address allocated for the group on that network. For a member network that is not directly attached the gateway creates a copy of the datagram with an additional inter-gateway header identifying the destination network. This inter-gateway datagram is forwarded to the nearest gateway on the destination network, using conventional store-and-forward routing techniques. At the gateway on the destination network, the datagram is stripped of its inter-gateway header and transmitted to the group's multicast address on that network. The datagram is dropped by the relaying gateways whenever it exceeds its distance limit.

The network membership records and the network-specific multicast structures are updated in response to group management requests from hosts. A host sends a request to create, join, or leave a group to an immediate neighbour gateway. If the host requests creation of a group, a new network membership record is created by the serving gateway and distributed to all other gateways. If the host is the first on its network to join a group, or if the host is the last on its network to leave a group, the group's network membership record is updated in all gateways. The updates need not be performed atomically at all gateways, due to the datagram delivery semantics; hosts can tolerate misrouted and lost packets caused by temporary gateway inconsistencies, as long as the inconsistencies are resolved within normal host retransmission periods. In this respect, the network membership data is similar to the network reachability data maintained by conventional routing algorithms, and can be handled by similar mechanisms.

In many cases, a host joins a group that already has members on the same network, or leaves a group that has remaining members on the same network. This is then a local matter between the hosts and gateways on a single network: only the local host membership table needs to be updated to include or exclude the host.

This basic implementation strategy meets the delivery requirements stated at the end of Section 4. However, it is far from optimal, in terms of either delivery efficiency or group management overhead. Below, we discuss some further refinements to the basic implementation.

6.2. Multicast Routing Between Networks

Multicast routing among the Internet gateways is similar to store-and-forward routing in a point-to-point network. The main difference is that the links between the nodes (gateways) can be a mixture of broadcast and unicast-type networks with widely different throughput and delay characteristics. In addition, packets are addressed to networks rather than hosts (at the gateway level).

We intend to use the extended reverse path forwarding algorithm of Dalal and Metcalfe [10]. Although originally designed for broadcast, it is a simple and efficient technique that can serve well for multicast delivery if network membership records in each gateway are augmented with information from neighbouring gateways. This algorithm uses the source network identifier, rather than a destination network identifier to make routing decisions. Since the source address of a datagram may be a group address, it cannot be used to identify the source network of the datagram; the first gateway must add a header specifying the source network. This approach minimizes redundant transmissions when multiple destination networks are reachable across a common intergateway link, a problem with the basic implementation described above.

Note that we eliminate from consideration techniques that fail to deliver along the branches of the shortest delay tree rooted at the source, such as Wall's center-based forwarding [16] because this compromises the meaning of the multicast distance parameter and detracts from multicast performance in general. We also rejected the approach of having a multicast packet carry more than one network identifier in its inter-gateway header to indicate multiple destination networks because the resulting variable length headers would cause buffering and fragmentation problems in the gateways.

6.3. Multicasting Within Networks

A simple optimization within a network is to have the sender use the local multicast address of a host group for its initial transmission. This allows the local host group members to receive the transmission immediately along with the gateways (which must now "eavesdrop" on all multicast transmissions). A gateway only forwards the datagram if the destination host group includes members on other networks. This scheme reduces the cost to reach local group members to one packet transmission from two required

in the basic implementation <3> so transmission to local members is basically as efficient as the local multicast support provided by the network.

A similar opportunity for reducing packet traffic arises when a datagram must traverse a network to get from one gateway to another, and that network also holds members of the destination group. Again, use of a network-specific multicast address which includes member hosts plus gateways can achieve the desired effect. However, in this case, hosts must be prepared to accept datagrams that include an inter-gateway header or, alternatively, every datagram must include a spare field in its header for use by gateways in lieu of an additional inter-gateway header.

6.4. Distributing Membership Information

A refinement to host group membership maintenance is to store the host group membership record for a group only in those gateways that are directly connected to member networks. Information about other groups is cached in the gateway only while it is required to route to those other groups. When a gateway receives a datagram to be forwarded to a group for which it has no network membership record (which can only happen if the gateway is not directly connected to a member network), it takes the following action. The gateway assumes temporarily that the destination group has members on every network in the internetwork, except those directly attached to the sending gateway, and routes the datagram accordingly. In the inter-gateway header of the outgoing packet, the gateway sets a bit indicating that it wishes to receive a copy of the network membership record for the destination host group. When such a datagram reaches a gateway on a member network, that gateway sends a copy of the membership record back to the requesting gateway and clears the copy request bit in the datagram.

Copies of network membership records sent to gateways outside of a group's member networks are cached for use in subsequent transmissions by those gateways. That raises the danger of a stale cache entry leading to systematic delivery failures. To counter that problem, the inter-gateway header contains a field which is a hash value or checksum on the network membership record used to route the datagram. Gateways on member networks compare the checksum on incoming datagrams with their up-to-date records. If the checksums don't match, an up-to-date copy of the record is returned to the gateway with the bad record.

This caching strategy minimizes intergateway traffic for groups

that are only used within one network or within the set of networks on which members reside, the expected common cases. Partial replication with caching also reduces the overhead for network traffic to disseminate updates and keep all copies consistent. Finally, it also reduces the total space required in all the gateways to support a large number of host groups.

We have not addressed here the problem of maintaining up-to-date, consistent network membership records within the set of gateways connected to members of a group. This can be viewed as a distributed database problem which has been well studied in other contexts. The loose consistency requirements on network membership records suggest that the techniques used in Grapevine [3] might be useful for this application.

7. Related Work

The use of unreliable multicast by higher-level protocols and the implementation of multicast within various individual networks have been well-studied (see [7] for references and discussion). However, there is relatively little published work on the use or implementation of internetwork multicasting.

Boggs, in his thesis [4], describes a number of distributed applications that are impossible or very awkward to support without the flexible binding nature of broadcast addressing. Although he recognizes that almost all of his applications would be best served by a multicast mechanism, he advocates the use of "directed broadcast" because it is easy to implement within many kinds of networks and can be extended across an internetwork without placing any new burden on internetwork gateways. In RFC-919 [13], Mogul proposes adopting directed broadcast for the DARPA Internet.

Broadcasting has the undesirable side effect of delivering packets to more hosts than necessary, thus incurring overhead on uninvolved parties and possibly creating security problems. As more and more applications take advantage of broadcasting, the overhead on all hosts continues to rise. Clearly, broadcast does not scale up to a large internetwork. As an attempt to handle the scaling problem, directed broadcast is less attractive than true multicast because the set of hosts that can be reached by a single "send" operation is an artifact of the internetwork topology, rather than a grouping that is meaningful to the sender.

In RFC-947 [12], Lebowitz and Mankins propose the use of broadcast

repeaters that pick up broadcast datagrams from one network and relay them to other networks for broadcast there. This technique is even less selective of its targets than Bogg's directed broadcast method.

Aguilar [1] suggests allowing an IP datagram to carry multiple destination addresses, which are used by the gateways to route the datagram to each recipient. Such a facility would alleviate some of the inefficiencies of sending individual datagrams to a group, but it would not be able to take advantage of local network multicast facilities. More seriously, Aguilar's scheme requires the sender to know the individual IP addresses of all members of the destination group and thus lacks the flexible binding nature of true multicast or broadcast.

8. Concluding Remarks

We have described a model of multicast communication for the Internet. As an extension of the existing Internet architecture, it views unicast communication and time-to-live constraints as special cases of the more general form of communication arising with multicast. We have argued that this model is implementable in the Internet and that it provides a powerful facility for a variety of applications. In some cases, it provides a facility that is required for certain applications to work in the Internet environment. In other cases, it provides a more efficient, robust and possibly more elegant way of implementing existing Internet applications.

We are currently implementing a prototype host group facility as an extension of IP. For practical reasons, this prototype implements all group management functions and multicast routing outside of the Internet gateways, in special hosts called multicast agents, which are similar to the broadcast repeaters of Lebowitz and Mankins. The collection of multicast agents in effect provides a second gateway system on top of the existing Internet, for multicast purposes. The major costs of this separation are redundancy of routing tables between gateways and multicast agents and the increased delay and unreliability of extra hops in the delivery path. Much of the routing information in the multicast agents must be "wired-in" because they do not have access to the gateways' routing tables. However, this rudimentary implementation provides an environment for evaluating the interface to the multicast service and for investigating group management and multicast routing protocols for eventual use in the gateways. It also serves as a testbed for porting multicast-based distributed applications to the Internet.

For now, we are restricting group membership to local networks that already have a broadcast or multicast capability, such as the

Ethernet. We feel that, in the future, any network that is to support hosts other than just gateways must have a multicast addressing mode. Efficient implementation of multicast within point-to-point or virtual circuit networks deserves investigation.

A significant issue raised by the host group model is authentication and access control in the Internet. Gateways must control which hosts can create and join host groups, presumably making their decision based on the identity of the requestor (thus requiring authentication) and permissions (access control lists). This issue does not arise in conventional internetwork architectures because host addresses are administratively assigned with no notion of dynamic assignment and binding as provided by host groups. We believe that access control should be recognized as a proper and necessary function of gateways so as to protect the hosts of local networks from general internetwork activity. Thus, group access control can be subsumed as part of this more general mechanism, although more investigation of the general issue is called for.

On a philosophical point, there has been considerable reluctance to make open use of multicast on local networks because it was network-specific and not provided across the Internet. We were originally of that school. However, we recognized that our "hidden" uses of multicast in the V distributed system were essential unless we resorted to dramatically poorer solutions - wired-in addresses. We also recognized, as described in this paper, that an adequate multicast facility for the Internet was feasible. As a consequence, we now argue that multicast is an important and basic facility to provide in local networks and internetworks. Higher levels of communication, including applications, should feel free to make use of this powerful facility. Networks and internetworks lacking multicast should be regarded as deficient relative to the future (and present) requirements of sophisticated distributed applications and communication systems.

Appendix I. Internet Group Management Protocol (IGMP)

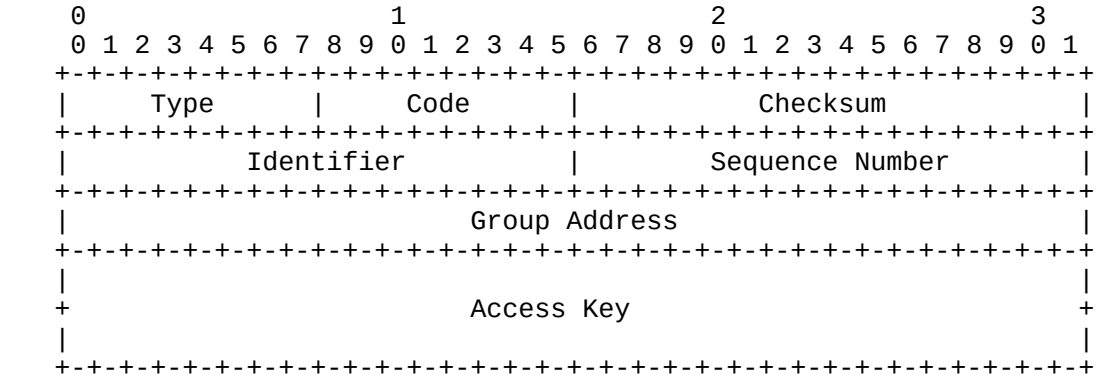
The Internet Group Management Protocol (IGMP) is used between IP hosts and their immediate neighbour multicast agents to support the allocation of temporary group addresses and the addition and deletion of members of a group.

Like ICMP, IGMP is a required part of all IP implementations. IGMP messages are encapsulated in IP datagrams, with an IP protocol number of 2. IGMP messages are formatted similarly to ICMP messages and the different IGMP message types are given values distinct from ICMP message types, so that both protocols may share common implementation modules or, perhaps, be merged into a single protocol.

IGMP interactions take the form of request-response transactions. A request message is sent by hosts to the permanent group of all immediate neighbour multicast agents. Multicast agents reply to the IP source address of a request. If no reply is received within a (currently unspecified) timeout interval, a host retransmits its request, up to some (currently unspecified) maximum number of times. IGMP transactions are considered idempotent, so that multicast agents need not recognize and filter out duplicate requests nor buffer replies <4>.

The IGMP message formats and procedures are defined below, in the style used in the ICMP specification.

Create Group Request or Create Group Reply Message



IP Fields:

Addresses

A Create Group Request message is sent with an individual IP address of the sending host as its source, and the well-known group address of the multicast agents as its destination.

The corresponding Create Group Reply is sent with those two addresses reversed.

IGMP Fields:

Type

101 for Create Group Request
102 for Create Group Reply

Code

For a Create Group Request message, the Code field indicates if the group is to be restricted:

0 = unrestricted
1 = restricted

For a Create Group Reply message, the Code field specifies the outcome of the request:

0 = request approved
1 = request denied, no resources

Checksum

The checksum is the 16-bit one's complement of the one's complement sum of the IGMP message starting with the IGMP Type. For computing the checksum, the checksum field should be zero. This checksum may be replaced in the future.

Identifier

An identifier to aid in matching Request and Reply messages.

Sequence Number

A sequence number to aid in matching Request and Reply messages.

Group Address

For a Create Group Request message, a value of 0.

For a Create Group Reply message, either a newly allocated group address (if the request is approved) or a value of 0 (if denied).

Access Key

For a Create Group Request message, a value of 0.

For a Create Group Reply message, either a pseudo-random 64-bit number (if the request for a restricted group is approved) or 0.

Description

A Create Group Request message is sent to the the group of local multicast agents by a host wishing to allocate a new temporary group.

If no Reply message is received within t seconds, the Request is retransmitted. If no Reply is received after n transmissions, the request is deemed to have failed.

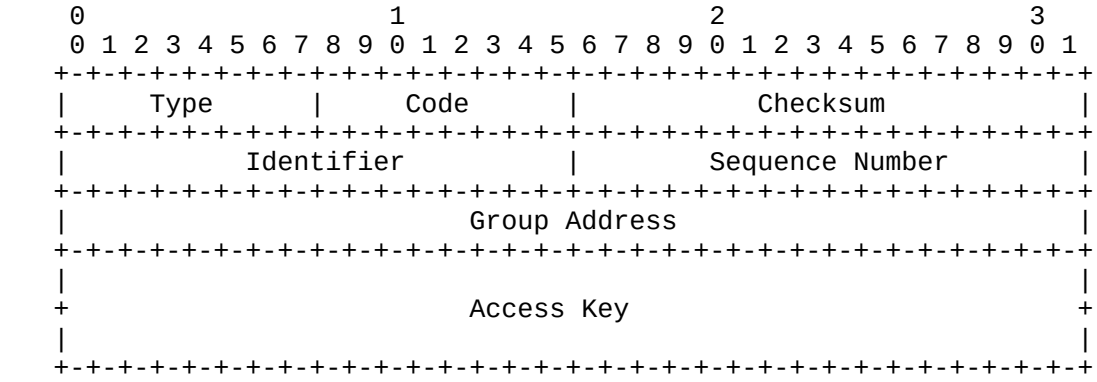
The first Reply message to arrive, if any, specifies the outcome of the request. The request may be denied because of lack of resources (e.g. no table space in gateways or all temporary addresses in use).

If the request is approved, the requesting host is considered to be the first and only current member of the new host group.

The Identifier and Sequence Number fields are used to match the Reply to the corresponding Request. The multicast agents may choose to use these values to minimize the chance of allocating more than one new group for a single request, for example when a Reply is lost and a

Request is retransmitted. However, the multicast agents must be prepared to recover temporary group addresses without requiring explicit Leave Group Requests from all members; they may choose simply to allocate a new address for every retransmission and recover unused ones when needed <5>.

Join Group Request or Join Group Reply Message



IP Fields:

Addresses

A Join Group Request message is sent with an individual IP address of the sending host as its source, and the well-known group address of the multicast agents as its destination.

The corresponding Join Group Reply is sent with those two addresses reversed.

IGMP Fields:

Type

103 for Join Group Request
104 for Join Group Reply

Code

For a Join Group Request message, the Code field contains 0.

For a Join Group Reply message, the Code field specifies the outcome of the request:

0 = request approved
1 = request denied, no resources
2 = request denied, invalid group address
3 = request denied, invalid access key

Checksum

The checksum is the 16-bit one's complement of the one's complement sum of the IGMP message starting with the IGMP Type. For computing the checksum, the checksum field should be zero. This checksum may be replaced in the future.

Identifier

An identifier to aid in matching Request and Reply messages.

Sequence Number

A sequence number to aid in matching Request and Reply messages.

Group Address

For a Join Group Request message, a host group address.

For a Join Group Reply message, the same group address as in the corresponding request.

Access Key

For a Join Group Request message, the access key allocated when the group was created (0 for unrestricted groups).

For a Join Group Reply message, the same access key as in the corresponding request.

Description

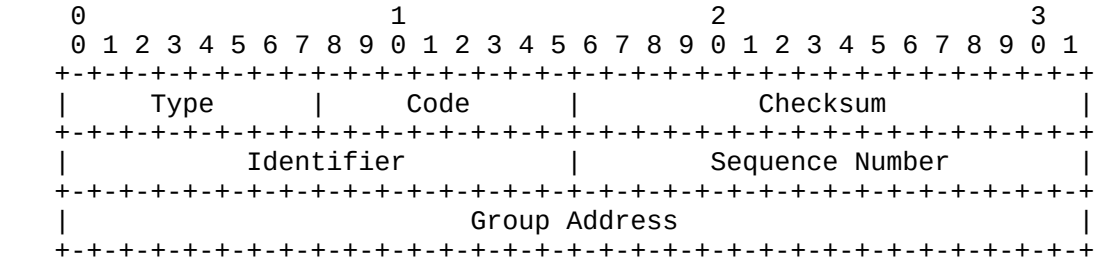
A Join Group Request message is sent to the the group of local multicast agents by a host wishing to join a specified, existing group. If no Reply message is received within t seconds, the Request is retransmitted. If no reply is received after n transmissions, the request is deemed to have failed.

The first Reply message to arrive, if any, specifies the outcome of the request. The request may be denied because of an invalid access key, an invalid specified group address (e.g. non-existent group) or lack of resources (e.g. no table space in gateways).

The Identifier and Sequence Number fields are used to match the Reply to the corresponding Request. If a multicast agent

receives a request from a host to join a group to which it already belongs, the agent approves the request, under the assumption that the request was a retransmission for a lost Reply.

Leave Group Request or Leave Group Reply Message



IP Fields:

Addresses

A Leave Group Request message is sent with an individual IP address of the sending host as its source, and the well-known group address of the multicast agents as its destination.

The corresponding Leave Group Reply is sent with those two addresses reversed.

IGMP Fields:

Type

105 for Leave Group Request
106 for Leave Group Reply

Code

For a Leave Group Request message, the Code field contains 0.

For Leave Group Reply message, the Code field specifies the outcome of the request:

0 = request approved
2 = request denied, invalid group address

Checksum

The checksum is the 16-bit one’s complement of the one’s complement sum of the IGMP message starting with the IGMP Type. For computing the checksum, the checksum field should be zero. This checksum may be replaced in the future.

Identifier

An identifier to aid in matching Request and Reply messages.

Sequence Number

A sequence number to aid in matching Request and Reply messages.

Group Address

For a Leave Group Request message, a host group address.

For a Leave Group Reply message, the same group address as in the corresponding request.

Description

A Leave Group Request message is sent to the the group of local multicast agents by a host wishing to leave a specified, existing group. If no Reply message is received within t seconds, the Request is retransmitted. If no reply is received after n transmissions, the request is deemed to have succeeded.

The first Reply message to arrive, if any, specifies the outcome of the request. The request may be denied only if the specified group address is invalid (e.g. an individual rather than a group address.)

The Identifier and Sequence Number fields are used to match the Reply to the corresponding Request, as with other ICMP transactions. If a multicast agent receives a request from a host to leave a group to which it does not belong, the agent approves the request, under the assumption that the request was a retransmission for a lost Reply.

Notes:

<1> In reality, Internet addresses (individual or group) are bound to network interfaces or network attachment points, not the host machines per se.

<2> In this procedure call notation, the arguments for an operation are listed in parentheses after the operation name, and the returned values, if any, are listed after a --> symbol.

<3> One unicast transmission from sender to gateway and one multicast transmission from gateway to local group members

<4> This protocol may eventually be replaced by a more general reliable transaction protocol designed for this type of client/server interaction, as suggested in RFC-955 [5].

<5> Multicast agents can use an ICMP Echo message to determine if a group has any current members. The Echo message should be transmitted several times before deciding the group address is no longer in use.

References

[1] L. Aguilar. Datagram Routing for Internet Multicasting. In ACM SIGCOMM ’84 Communications Architectures and Protocols, pages 58-63. ACM, June, 1984.

[2] E. J. Berglund and D. R. Cheriton. Amaze: A distributed multi-player game program using the distributed V kernel. In Proceedings of the Fourth International Conference on Distributed Systems. IEEE, May, 1984.

[3] A. D. Birrell et al. Grapevine: an exercise in distributed computing. Communications of the ACM 25(4):260-274, April, 1982.

[4] D. R. Boggs. Internet Broadcasting. PhD thesis, Stanford University, January, 1982.

[5] R. Braden. Towards a Transport Service for Transaction Processing Applications. Technical Report RFC-919, SRI Network Information Center, September, 1985.

[6] J-M. Chang. Simplifying Distributed Database Design by Using a Broadcast Network. In SIGMOD ’84. ACM, June, 1984.

[7] D. R. Cheriton and S. E. Deering. Host Groups: A Multicast Extension for Datagram Internetworks. In Proceedings of the Ninth Data Communications Symposium. ACM/IEEE, September, 1985.

[8] D. R. Cheriton and W. Zwaenepoel. Distributed Process Groups in the V Kernel. ACM Transactions on Computer Systems 3(3), May, 1985.

[9] F. Cristian et al. Atomic Broadcast: from simple message diffusion to Byzantine agreement. In 15th International Conference on Fault Tolerant Computing. , Ann Arbor, Michigan, June, 1985.

[10] Y. K. Dalal and R. M. Metcalfe. Reverse Path Forwarding of Broadcast Packets. Communications of the ACM 21(2):1040-1047, December, 1978.

[11] H. Forsdick. MMCF: A Multi-Media Conferencing Facility. personal communication.

[12] K. Lebowitz and D. Mankins. Multi-network Broadcasting within the Internet.Technical Report RFC-947, SRI Network Information Center, June, 1985.

[13] J. Mogul. Broadcasting Internet Datagrams. Technical Report RFC-919, SRI Network Information Center, October, 1984.

[14] J. Postel. Internet Protocol. Technical Report RFC-791, SRI Network Information Center, September, 1981.

[15] J. Postel. Internet Control Message Protocol. Technical Report RFC-792, SRI Network Information Center, September, 1981.

[16] D. W, Wall. Mechanisms for Broadcast and Selective Broadcast. Technical Report 190, Computer Systems Laboratory, Stanford University, June, 1980.

[17] J. K. Reynolds and J. Postel. Assigned Numbers. Technical Report RFC-960, SRI Network Information Center, September, 1981.