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IGMP/MLD Optimizations in Wireless and Mobile Networks
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Abstract

This document proposes a variety of optimization approaches for IGMP and MLD in wireless and mobile networks. It aims to provide useful guidelines to allow efficient multicast communication in these networks using IGMP or MLD protocols.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

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1. Introduction

The deployments of various wireless access techniques are being combined with the use of video and other applications which rely upon IP Multicast. Wireless and mobile multicast are attracting increasing interest from content and service providers. Multicast faces challenges with dynamic group membership management being under the constant update of delivery paths introduced by node movement. There is a high probability of loss and congestion due to limited reliability and capacity of wireless links.

Multicast networks are generally constructed by the IGMP and MLD group management protocols (respectively for IPv4 and IPv6 networks) to track valid receivers and by multicast routing protocol building multicast delivery paths. This document focuses only on IGMP and MLD, the protocols used by a host to subscribe to a multicast group and the protocols that are most likely to be exposed to wireless links when supporting terminal mobility. As IGMP and MLD were designed for fixed users on a wired link, they do not necessarily work well for different wireless link types and mobile scenarios. IGMP/MLD should be enhanced to be more applicable in these mobile/wireless environments.

This memo proposes a variety of optimizations for IGMP and MLD, in wireless and mobile networks, to improve network performance, with minimum changes on the protocol behavior and without introducing interoperability issues. These solutions can also be applied in wired networks when efficiency or reliability is required.

For generality, this memo does not put limitations on the type of wireless techniques running below IGMP or MLD. They could be cellular, WiMAX, WiFi and etc, and are modeled as different abstract link models as described in section 2.2. Even though some of them (such as WiFi) have multicast limitations, it is probable that IGMP/MLD is enabled on the wireless terminal and multicast is supported across the network. The mobile IP protocol adopted on the core side, upstream from the access router, could be PMIP, MIPv4, or MIPv6.

2. Requirements

2.1. Characteristics of Wireless and Mobile Multicast

Several limitations should be considered when supporting IP multicast in wireless and mobile networks, including:

- O Limited link bandwidth: wireless links usually have limited bandwidth, and the situation will be made even worse if a high volume

of video multicast data has to be carried. Additionally, the bandwidth available in the upstream and downstream directions may be asymmetrical.

O High loss rate: wireless links usually have packet loss ranging from 1% to 30% according to different links types and conditions. Also when packets have to travel between home and access networks (e.g. through a tunnel), they are prone to loss if the two networks are distant from each other.

O Frequent membership change: in fixed multicast, membership change only happens when a user leaves or joins a group, while in mobile scenario membership may also change when a user changes its location.

O Prone to performance degradation: the possible increased interaction of protocols across layers for mobility management, and the limitation of link capacity, may lead to network performance degradation and even to complete connection loss.

O Increased Leave Latency: the leave latency in mobile multicast might be increased due to user movement, especially if the traffic has to be transmitted between access and home networks, or if there is a handshake between networks.

2.2. Wireless Link Model

Wireless links can typically be categorized into three models: point-to-point (PTP), point-to-multipoint (PTMP), and broadcast link models.

In the PTP model, one link is dedicated for two communication facilities. For multicast transmission, each PTP link normally has only one receiver and the bandwidth is dedicated for that receiver. Such link model may be implemented by running PPP on the link or having separate VLAN assignment for each receiver. In a mobile network, a tunnel between entities of home and foreign networks should be recognized as a PTP link.

PTMP is the model for multipoint transmission wherein there is one centralized transmitter and multiple distributed receivers. PTMP provides common downlink channels for all receivers and dedicated uplink channel for each receiver. Bandwidth downstream is shared by all receivers on the same link.

Broadcast links can connect two or more nodes and support broadcast transmissions. It is quite similar to fixed Ethernet link model and its link resource is shared in both uplink and downlink directions.

2.3. Requirements on IGMP and MLD

IGMP and MLD are usually run between mobile or wireless terminals and their first-hop access routers (i.e. home or foreign routers) to subscribe to a IP multicast channel. Currently the version in-use includes IGMPv2 [RFC2236] and its IPv6 counterpart MLDv1 [RFC2710], IGMPv3 [RFC3376] and its IPv6 counterpart MLDv2 [RFC3810], and LW-IGMPv3/MLDv2 [RFC5790]. All these versions have basic group management capability required by a multicast subscription. The differences lie in that IGMPv2 and MLDv1 can only join and leave a non-source-specific group, while IGMPv3 and MLDv2 can select including and excluding specific sources for their join and leave operation, and LW-IGMPv3/MLDv2 simplifies IGMPv3/MLDv2 procedures by discarding excluding-source function. Among these versions, (LW-)IGMPv3/MLDv2 has the capability of explicitly tracking each host member.

From the illustration given in section 2.1 and 2.2, it is desirable for IGMP and MLD to have the following characteristics when used in wireless and mobile networks:

- o Adaptive to link conditions: wireless networks have various link types, each with different bandwidth and performance features. IGMP or MLD should be able to be adaptive to different link models and link conditions to optimize its protocol operation.
- o Minimal group join/leave latency: because mobility and handover may cause a user to join and leave a multicast group frequently, fast join and leave by the user helps to accelerate service activation and to release unnecessary resources quickly to optimize resource utilization.
- o Robust to packet loss: the unreliable packet transmission due to instable wireless link conditions and limited bandwidth, or long distance transmission in mobile network put more strict robustness requirement on delivery of IGMP and MLD protocol messages.
- o Reducing packet exchange: wireless link resources are usually more limited, precious, and congested compared to their wired counterpart. This requires packet exchange be minimized without degrading protocol performance.
- o Packet burst avoidance: large number of packets generated in a short time interval may have the tendency to deteriorate wireless network conditions. IGMP and MLD should be optimized to reduce the probability of packet burst.

3. IGMP/MLD Optimization for Wireless and Mobile Networks

This section introduces several optimizations for IGMP and MLD in wireless or mobile environment. The aim is to meet the requirements described in section 2.3. It should be noted that because an enhancement in one direction might result in weakening effect in another, balances should be taken cautiously to realize overall performance elevation.

3.1. Switching Between Unicast and Multicast Queries

IGMP/MLD protocols use multicast Queries whose destinations are multicast addresses and also allows use of unicast Query with unicast destination to be sent only to one host. Unicast Query has the advantage of not affecting other hosts on the same link, and is desirable for wireless communication because a mobile terminal often has limited battery power [RFC6636]. But if the number of valid receivers is large, using unicast Query for each receiver is inefficient because large number of Unicast Queries have to be generated, in which situation normal multicast Query will be a good choice because only one General Query is needed. If the number of receivers to be queried is small, unicast Query is advantageous over the multicast one.

More flexibly, the router can choose to switch between unicast and multicast Queries according to the practical network conditions. For example, if the receiver number is small, the router could send unicast Queries respectively to each receiver, without arousing other non-member terminal which is in dormant state. When the receiver number reaches a predefined level, the router could change to use multicast Queries. To have the knowledge of the number of the valid receivers, a router is required to enable explicit tracking, and because Group-Specific Query and Group-and-Source-Specific Query are usually not used under explicit tracking [RFC6636], the switching operation mostly applies to General Queries.

3.2. General Query Supplemented with Unicast Query

The Unicast Query can be used in assistance to General Query to improve the robustness of solicited reports when General Query fails to collect all of its valid members. It requires the explicit tracking to be enabled and can be used when a router after sending a periodical General Query collects successfully most of the valid members' responses while losing some of which are still valid in its database. This may be because these reports are not generated or generated but lost for some unknown reasons. The router could choose to unicast a Query respectively to each non-respondent valid receiver to check whether they are still alive for the multicast reception,

without affecting the majority of receivers that have already responded. Unicast Queries under this condition could be sent at the end of the [Maximum Response Delay] after posting a General Query, and be retransmitted for [Last Member Query Count] times, at an interval of [Last Member Query Interval].

3.3. Retransmission of Queries

In IGMP and MLD, apart from the continuously periodical transmission, General Query is also transmitted during a router's startup. It is transmitted for [Startup Query Count] times by [Startup Query Interval]. There are some other cases where retransmission of General Query is beneficial which are not covered by current IGMP and MLD protocols as shown as following.

For example, a router which keeps track of all its active receivers, if after sending a General Query, fails to get any response from the receivers which are still valid in its membership database. This may be because all the responses of the receivers happen to be lost, or the sent Query does not arrive at the other side of the link to the receivers. The router could compensate this situation by retransmitting the General Query to solicit its active members. The retransmission can also be applied to Group-Specific or Group-and-Source-Specific Query on a router without explicit tracking capability, when these Specific Queries cannot collect valid response, to prevent missing valid members caused by lost Queries and Reports.

The above compensating Queries could be sent [Last Member Query Count] times, at the interval of [Last Member Query Interval], if the router cannot get any feedback from the receivers.

3.4. General Query Suppression

In IGMP and MLD, the General Query is sent periodically and continuously without any limitation. It helps soliciting the state of current valid member but has to be processed by all hosts on the link, whether they are valid multicast receivers or not. When there is no receiver, the transmission of the General Query is a waste of resources for both the host and the router.

An IGMP/MLD router could suppress its transmission of General Query if it knows there is no valid multicast receiver on an interface, e.g. in the following cases:

O When the last member reports its leave for a group. This could be judged by an explicit tracking router checking its membership database, or by a non-explicit-tracking router getting no response

after sending Group-Specific or Group-and-Source-Specific Query.

O When the only member on a PTP link reports its leaving

O When a router after retransmitting General Queries on startup fails to get any response

O When a router previously has valid members but fails to get any response after several rounds of General Queries.

In these cases the router could make the decision that no member is on the interface and totally stop its transmission of periodical General Queries. If afterwards any valid member joins a group, the router could resume the original cycle of general Querying. Because General Query influences all hosts on a link, suppressing it when it is not needed is beneficial for both the link efficiency and terminal power saving.

3.5. Tuning Response Delay According to Link Type and Status

IGMP and MLD use delayed response to spread unsolicited Reports from different hosts to reduce possibility of packet burst. This is implemented by a host responding to a Query in a specific time randomly chosen between 0 and [Maximum Response Delay], the latter of which is determined by the router and is carried in Query messages to inform the hosts for calculation of the response delay. A larger value will lessen the burst better but will increase leave latency (the time taken to cease the traffic flowing after the last member requests the escaping of a channel).

In order to avoid message burst and reduce leave latency, the Response Delay may be dynamically calculated based on the expected number of responders, and link type and status, as shown in the following:

O If the expected number of reporters is large and link condition is bad, longer Maximum Response Delay is recommended; if the expected number of reporters is small and the link condition is good, smaller Maximum response Delay should be set.

o If the link type is PTP, the Maximum Response Delay can be chosen smaller, whereas if the link is PTMP or broadcast medium, the Maximum Response Delay can be configured larger.

The Maximum Response Delay could be configured by the administrator as mentioned above, or be calculated automatically by a software tool implemented according to experiential model for different link modes. The measures to determine the instant value of Maximum Response Delay

are out of this document's scope.

3.6. Triggering Reports and Queries Quickly During Handover

When a mobile terminal is moving from one network to another, if it is receiving multicast content, its new access network should try to deliver the content to the receiver without disruption or performance deterioration. In order to implement smooth handover between networks, the terminal's membership should be acquired as quickly as possible by the new access network.

An access router could trigger a Query to a terminal as soon as it detects the terminal's attaching on its link. This could be a General Query if the number of the entering terminals is not small (e.g when they are simultaneously in a moving train). Or this Query could also be a unicast Query for this incoming terminal to prevent unnecessary action of other terminals in the switching area.

For the terminal, it could send a report immediately if it is currently in the multicast reception state, when it begins to connect the new network. This helps establishing more quickly the membership state and enable faster multicast stream injection, because with the active report the router does not need to wait for the query period to acquire the terminal's newest state.

4. Applicability and Interoperability Considerations

Among the optimizations listed above, 'Switching between unicast and multicast Queries'(3.1) and 'General Query Supplemented with Unicast Query'(3.2) requires a router to know beforehand the valid members connected through an interface, thus require explicit tracking capability. An IGMP/MLD implementation could choose any combination of the methods listed from 3.1 to 3.6 to optimize multicast communication on a specific wireless or mobile network.

For example, an explicit-tracking IGMPv3 router, can switch to unicast General Queries if the number of members on a link is small (3.1), can trigger unicast Query to a previously valid receiver if failing to get expected responses from it (3.2), can retransmit a General Query if after the previous one cannot collect reports from all valid members (3.3), and can stop sending a General Query when the last member leaves the group (3.4), and etc.

For interoperability, it is required if multiple multicast routers are connected to the same network for redundancy, each router are configured with the same optimization policy to synchronize the membership states among the routers.

5. IGMP/MLD Suspend and Resume

5.1. IGMP/MLD Suspend Request

IGMP/MLD Suspend is an operation triggered by a host that subscribes multicast channels or an IGMP/MLD proxy [refs.Proxy] to which hosts subscribing multicast channels attached. An IGMP/MLD Suspend message requests an adjacent upstream router to suspend forwarding subscribed data, while to keep the subscription state (i.e., not to prune the routing path). It is useful especially in a mobile network. When a mobile host moves from a current network (i.e., a mobile host's point of attachment) to a different network, an IGMP/MLD Suspend message is sent by the host itself (or an IGMP/MLD proxy to which mobile hosts attached).

When an IGMP/MLD proxy receives IGMP/MLD Suspend messages on its downstream interface, it forwards the Suspend message to its upstream router via its upstream interface if needed (see Section 5.3).

5.2. IGMP/MLD Resume Request

When a host that has subscribed multicast channels and sent IGMP/MLD Suspend messages attaches to a new network, it immediately sends IGMP/MLD Resume messages to request its upstream router to resume forwarding the data. The Resume Records specified in the IGMP/MLD Resume message will be the same as that of the Suspend Records the host sent.

5.3. IGMP/MLD Suspend Reception

When a multicast router receives an IGMP/MLD Suspend message from the downstream member hosts or IGMP/MLD proxy, it examines whether the message sender is the sole member of the reported channels at the downstream link or not. There are two ways to know it. One is done by the Group-Specific or Group-and-Source Specific Queries. The other is done by the explicit tracking function [refs.explicit].

The router sends the Group-Specific or Group-and-Source Specific Queries for all records in the Suspend messages. If the router receives IGMP/MLD reports including some or all of the Suspend Records, it eliminates the reported records from the Suspend Records and keeps forwarding these data. If the router does not receive IGMP/MLD reports for some or all of the Suspend Records, it recognizes that the Suspend message sender is the sole member host for these channels on the link. After the router organizes the new Suspend Records (that eliminate reported records from the original one), it suspends data forwarding for them.

The explicit tracking function gives advantage of organizing the new Suspended Records. If a router enables the explicit tracking function, it can recognize whether the message sender host is the sole member without sending the Group-Specific or Group-and-Source Specific Queries. Then the router suspends data forwarding based on the up-to-date Suspend Records.

The multicast router maintains Suspend Records until it receives the corresponding IGMP/MLD Resume message (described in the next section) or the IGMP/MLD Suspend Interval timer (described in Section 6.1) is expired. When either the Resume message reception or the timer expiration occurs, the router resume data forwarding for the Suspend Records and discards the Suspend Records.

If a multicast router receives an IGMP/MLD Suspend message, which includes Multicast Address Records already suspended, the router restarts the IGMP/MLD Suspend Interval timer for the corresponding Multicast Address Records.

When an IGMP/MLD proxy receives an IGMP/MLD Suspend message from a downstream host, it behaves as a multicast router as described above, because the proxy device performs the router portion of the IGMP or MLD protocol on its downstream interfaces.

When a mobile node that has sent the IGMP/MLD Suspend message receives the corresponding Group-Specific or Group-and-Source Specific Queries for the Suspend Records, it replies the standard IGMP/MLD Report messages as defined in [refs.IGMPv3][refs.MLDv2].

5.4. IGMP/MLD Resume Reception

When a multicast router receives an IGMP/MLD Resume message, the router examines the message sender and an IGMP/MLD Suspend Interval timer. If the router has the Suspend Records given from the Resume message sender, it compares the Suspend Records with the notified Multicast Address Records specified in the Resume message. For the matched Multicast Address Records, the router then removes the entries from the Suspend Records and resumes data forwarding with restarting the group or source timers. For the mismatched Multicast Address Records, the router keeps unchanged (then will be removed by timeout) or explicitly starts the leave (or prune) procedures for the channels, while it depends on the implementation.

If either the router does not have the corresponding Suspend Records or the IGMP/MLD Suspend Interval timer has expired, then the router does not take any action.

If a router that did not recognize an IGMP/MLD Suspend message (e.g.,

due to packet loss or some troubles in its transmission) receives an IGMP/MLD Resume message, it will accept the message as a regular Current-State Report IGMP/MLD message.

6. Timers, Counters, and Their Default Values

6.1. IGMP/MLD Suspend Interval Timer

After a multicast router receiving an IGMP/MLD Suspend message will identify the corresponding multicast sessions/channels, it suspends data forwarding and keeps the Suspend Records until the given amount of timer value is expired. This timer is named the "IGMP/MLD Suspend Interval timer", which is a configurable value.

The Suspend Interval is used to allow a multicast router to resume the multicast session. Therefore, if the multicast router does not receive the corresponding IGMP/MLD Resume message for the IGMP/MLD Resume operation within the Suspend Interval, it leaves the sessions/channels recorded in the Suspend Records and discards the Suspend Records. Note that the router does not send any IGMP/MLD Query message for the timeout sessions/channels and immediately leaves from them.

7. IANA Considerations

This document makes no request of IANA.

Note to RFC Editor: this section may be removed on publication as an RFC.

8. Security Considerations

Since the methods only involve the tuning of protocol behavior by e.g. retransmission, changing delay parameter, or other compensating operations, they do not introduce additional security weaknesses. The security considerations described in [RFC2236], [RFC3376], [RFC2710] and [RFC3810] can be reused. And to achieve some security level in insecure wireless network, it is possible to take stronger security procedures during IGMP/MLD message exchange, which are out of the scope of this memo.

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