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Tuning the Behavior of the Internet Group Management Protocol (IGMP) and Multicast Listener Discovery (MLD) for Routers in Mobile and Wireless Networks

Abstract

The Internet Group Management Protocol (IGMP) and Multicast Listener Discovery (MLD) are the protocols used by hosts and multicast routers to exchange their IP multicast group memberships with each other. This document describes ways to achieve IGMPv3 and MLDv2 protocol optimization for mobility and aims to become a guideline for the tuning of IGMPv3/MLDv2 Queries, timers, and counter values.

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1. Introduction

The Internet Group Management Protocol (IGMP) [1] for IPv4 and the Multicast Listener Discovery (MLD) [2] protocol for IPv6 are the standard protocols for hosts to initiate joining or leaving of multicast sessions. These protocols must also be supported by multicast routers or IGMP/MLD proxies [5] that maintain multicast membership information on their downstream interfaces. Conceptually, IGMP and MLD work on both wireless and mobile networks. However, wireless access technologies operate on a shared medium or a point-to-point link with limited spectrum and bandwidth. In many wireless regimes, it is desirable to minimize multicast-related signaling to preserve the limited resources of battery-powered mobile devices and the constrained transmission capacities of the networks. The motion of a host may cause disruption of multicast service initiation and termination in the new or previous network. Slow multicast service activation following a join may incur additional delay in receiving multicast packets and degrade reception quality. Slow service termination triggered by a rapid departure of the mobile host without first leaving the group in the previous network may waste network resources.

When IGMP and MLD are used with mobile IP protocols, the proximity of network entities should be considered. For example, when a bidirectional tunnel is used with the mobility entities described in [6] and [7], the mobile host experiences additional latency because the round-trip time using a bidirectional tunnel between mobility entities is larger compared to the case where a host and an upstream router attach to a LAN.

This document describes ways to tune IGMPv3 and MLDv2 protocol behavior -- on the multicast router and proxy side -- concentrating in particular on wireless and mobile networks, including the tuning of queries and related timers. This selective optimization provides tangible benefits to mobile hosts and routers by keeping track of the membership status of downstream hosts, and of various IGMP/MLD Query types and values, in order to appropriately tune the number of response messages. This document does not make any changes to the IGMPv3 and MLDv2 protocols and only suggests optimal settings for the configurable parameters of the protocols in mobile and wireless environments.

2. Terminology

In this document, "router" means both a multicast router and an IGMP/MLD proxy.

3. Explicit Tracking of Membership Status

Mobile hosts use IGMP and MLD to make a request to join or leave multicast sessions. When an adjacent upstream router receives the IGMP/MLD Report messages, it recognizes the membership status on the link. To update the membership status reliably, the router sends IGMP/MLD Query messages periodically, and sends Group-Specific and/or Group-and-Source-Specific Queries when a member host reports its leave. An IGMP/MLD Query is therefore necessary to obtain up-to-date membership information, but a large number of the reply messages sent from all member hosts may cause network congestion or consume network bandwidth.

The "explicit tracking function" [8] is a possible approach to reduce the transmitted number of IGMP/MLD messages and contribute to the efficiency of mobile communications. It enables the router to keep track of the membership status of the downstream IGMPv3 or MLDv2 member hosts. That is, if a router enables the explicit tracking function, it does not always need to request transmission of a Current-State Report message from the receiver hosts, since the router implicitly recognizes the (potential) last member host when it receives the State-Change Report message reporting a leave. The router can therefore send IGMP/MLD Group-Specific and Group-and-Source-Specific Queries LMQC/LLQC times (see Section 4.3) only when it recognizes that the last member has left the network. This reduces the transmitted number of Current-State Report messages.

Enabling the explicit tracking function is advantageous for mobile multicast, but the function requires additional processing capability and, possibly, substantial memory for routers to store all membership status information. This resource requirement is potentially impacted, especially when a router needs to maintain a large number of receiver hosts. Therefore, this document recommends that adjacent upstream multicast routers enable the explicit tracking function for IP multicast communications on wireless and mobile networks, if they have enough resources. If operators think that their routers do not have enough resources, they may disable this function on their routers. Note that whether or not routers enable the explicit tracking function, they need to maintain downstream membership status by sending IGMPv3/MLDv2 General Query messages, as some IGMPv3/MLDv2 messages may be lost during transmission.

4. Tuning IGMP/MLD Timers and Values

4.1. Tuning the IGMP/MLD General Query Interval

IGMP and MLD are unreliable protocols; to cover the possibility of a State-Change Report being missed by one or more multicast routers, hosts retransmit the same State-Change Report messages ([Robustness Variable] - 1) more times, at intervals chosen at random from the range (0, [Unsolicited Report Interval]) [1] [2]. Although this behavior increases the protocol's robustness, it does not guarantee that the State-Change Report reaches the routers. Therefore, routers still need to refresh their downstream membership information by receiving a Current-State Report, as periodically solicited by an IGMP/MLD General Query sent in the [Query Interval] period, in order to enhance robustness of the host in case of link failures and packet loss. This procedure also supports situations where mobile hosts are powered off or moved from one network to another network managed by a different router without any notification (e.g., a leave request).

The [Query Interval] is the interval between General Queries sent by the regular IGMPv3/MLDv2 querier; the default value is 125 seconds [1] [2]. By varying the [Query Interval], multicast routers can tune the number of IGMP/MLD messages on the network; larger values cause IGMP/MLD Queries to be sent less often.

This document proposes a [Query Interval] value of 150 seconds by changing the Querier's Query Interval Code (QQIC) field in the IGMP/MLD Query message, for the case where a router that enables the explicit tracking function potentially operates a large number of member hosts, such as more than 200 hosts on the wireless link. This longer interval value contributes to minimizing Report message traffic and battery-power consumption for mobile hosts.

On the other hand, this document also proposes a [Query Interval] value of 60 to 90 seconds for the case where a router that enables the explicit tracking function attaches to a higher-capacity wireless link. This shorter interval contributes to quick synchronization of the membership information tracked by the router but may consume battery power on mobile hosts.

If a router does not enable the explicit tracking function, the [Query Interval] value would be its default value -- 125 seconds.

In situations where Mobile IPv6 [7] is used, when the home agent implements multicast router functionality and multicast data packets are tunneled to and from the home agent, the home agent may want to increase the query interval. This happens, for example, when the home agent detects network congestion. In this case, the home agent starts forwarding queries with the default [Query Interval] value and increases the value in a gradual manner.

4.2. Tuning the IGMP/MLD Query Response Interval

The [Query Response Interval] is the Max Response Time (or Max Response Delay) used to calculate the Max Resp Code inserted into the periodic General Queries. Its default value is 10 seconds, expressed as "Max Resp Code=100" for IGMPv3 [1] and "Maximum Response Code=10000" for MLDv2 [2]. By varying the [Query Response Interval], multicast routers can tune the burstiness of IGMP/MLD messages on the network; larger values make the traffic less bursty, as the hosts' responses are spread out over a larger interval, but will increase join latency when a State-Change Report (i.e., join request) is missing.

According to our experimental analysis, this document proposes two scenarios for tuning the [Query Response Interval] value in different wireless link conditions: one scenario is for a wireless link with lower resource capacity or a lossy link, and the other scenario is for a wireless link with enough capacity or whose condition is reliable enough for IGMP/MLD message transmission.

Regarding the first scenario, for instance, when a multicast router attaches to a bursty IEEE 802.11b link, the router configures a longer [Query Response Interval] value, such as 10 to 20 (seconds). This configuration will reduce congestion of the Current-State Report messages on a link but may increase join latency and leave latency when the unsolicited messages (State-Change Records) are lost on the router. Note that as defined in Section 4.1.1 of [1], in IGMPv3, a Max Resp Code larger than 128 represents the exponential values and changes the granularity. For example, if one wants to set the Max Response Time to 20.0 seconds, the Max Resp Code should be expressed as "0b10001001", which is divided into "mant=0b1001" and "exp=0b000".

The second scenario may happen for a multicast router attaching to a wireless link having higher resource capacity or to a point-to-(multi-)point link such as an IEEE 802.16e link because IGMP/MLD messages do not seriously affect the condition of the link. The router can seek Current-State Report messages with a shorter [Query Response Interval] value, such as 5 to 10 (seconds). This configuration will contribute to (at some level) quickly discovering non-tracked member hosts and synchronizing the membership information.

4.3. Tuning the Last Member Query Timer (LMQT) and Last Listener Query Timer (LLQT)

Shortening the Last Member Query Timer (LMQT) for IGMPv3 and the Last Listener Query Timer (LLQT) for MLDv2 contributes to minimizing leave latency. LMQT is represented by the Last Member Query Interval (LMQI) multiplied by the Last Member Query Count (LMQC), and LLQT is represented by the Last Listener Query Interval (LLQI) multiplied by the Last Listener Query Count (LLQC).

While LMQI and LLQI are changeable, it is reasonable to use the default value (i.e., 1 second) for LMQI and LLQI in a wireless network. LMQC and LLQC, whose default value is the [Robustness Variable] value, are also tunable. Therefore, LMQC and LLQC can be set to "1" for routers that enable the explicit tracking function, and then LMQT and LLQT are set to 1 second. However, setting LMQC and LLQC to 1 increases the risk of missing the last member; LMQC and LLQC ought to be set to 1 only when network operators think that their wireless link is stable enough.

On the other hand, if network operators think that their wireless link is lossy (e.g., due to a large number of attached hosts or limited resources), they can set LMQC and LLQC to "2" for their routers that enable the explicit tracking function. Although bigger LMQC and LLQC values may cause longer leave latency, the risk of missing the last member will be reduced.

4.4. Tuning the Startup Query Interval

The [Startup Query Interval] is the interval between General Queries sent by a querier on startup. The default value is 1/4 of [Query Interval]; however, a shortened value, such as 1 second, would help contribute to shortening handover delay for mobile hosts in, for example, the base solution with Proxy Mobile IPv6 (PMIPv6) [9]. Note that the [Startup Query Interval] is a static value and cannot be changed by any external signal. Therefore, operators who maintain routers and wireless links need to properly configure this value.

4.5. Tuning the Robustness Variable

To cover the possibility of unsolicited reports being missed by multicast routers, unsolicited reports are retransmitted ([Robustness Variable] - 1) more times, at intervals chosen at random from the defined range [1] [2]. The QRV (Querier's Robustness Variable) field in the IGMP/MLD Query contains the [Robustness Variable] value used by the querier. The default [Robustness Variable] value defined in IGMPv3 [1] and MLDv2 [2] is "2".

This document proposes "2" for the [Robustness Variable] value for mobility when a router attaches to a wireless link having lower resource capacity or a large number of hosts. For a router that attaches to a higher-capacity wireless link known to be reliable, retransmitting the same State-Change Report message is not required; hence, the router sets the [Robustness Variable] to "1".

4.6. Tuning Scenarios for Various Mobile IP Networks

In mobile IP networks, IGMP and MLD are used with three deployment scenarios: (1) running directly between a host and access router on a wireless network, (2) running between a host and home router through a tunnel link, and (3) running between a home router and foreign router through a tunnel link.

When a receiver host connects directly through a wireless link to a foreign access router or a home router, the tuning of the IGMP/MLD protocol parameters should be the same as suggested in the previous sections. The example of this scenario occurs when in PMIPv6 [6], the mobile access gateway, whose role is similar to a foreign router, acts as a multicast router or proxy.

The second scenario occurs when a bidirectional tunnel established between a host and home router is used to exchange IGMP/MLD messages [7] [10]. Tuning the parameters is difficult in this situation because the condition of the tunnel link is diverse and changeable. When a host is far away from the home router, the transmission delay between the two entities may be longer and the packet delivery may be more unreliable. Thus, the effects of IGMP/MLD message transmission through a tunnel link ought to be considered when parameters are set. For example, the [Query Interval] and [Query Response Interval] could be set shorter to compensate for transmission delay, and the [Robustness Variable] could be increased to compensate for possible packet loss.

The third scenario occurs in [9], in which the mobile access gateway (i.e., foreign router) acts as the IGMP/MLD Proxy [5] in PMIPv6 [6]. Through the bidirectional tunnel established with the local mobility anchor (i.e., home router), the mobile access gateway sends summary reports of its downstream member hosts to the local mobility anchor. Apart from the distance factor, which influences the parameter setting, the [Query Response Interval] on the local mobility anchor could be set to a smaller value because the number of mobile access gateways is much smaller compared to the number of hosts, and the chance of packet burst is low for the same reason. Additionally, the power consumption due to a lower query interval is not an issue for the mobile access gateways because the mobile access gateways are usually not battery-powered.

Ideally, the IGMP/MLD querier router adjusts its parameter settings according to the actual mobile IP network conditions to benefit service performance and resource utilization. It would be desirable for a home router to determine the aforementioned timers and values according to the delay between the initiating IGMP/MLD Query and the responding IGMP/MLD Report. However, describing how these timers and values can be dynamically adjusted is out of scope for this document.

5. Destination Address of a Specific Query

IGMP/MLD Group-Specific and Group-and-Source-Specific Queries defined in [1] and [2] are sent to verify whether there are hosts that desire reception of the specified group or a set of sources, or to rebuild the desired reception state for a particular group or a set of sources. These specific queries build and refresh the multicast membership state of hosts on an attached network.

Group-Specific Queries are sent with an IP destination address equal to the multicast address of interest, as defined in [1] and [2]. Using the multicast group of interest in the specific query is preferred in this environment because hosts that do not join the multicast session do not pay attention to these specific queries, and only active member hosts that have been receiving multicast contents with the specified address reply to IGMP/MLD Reports.

6. Interoperability

IGMPv3 [1] and MLDv2 [2] provide the ability for hosts to report source-specific subscriptions. With IGMPv3/MLDv2, a mobile host can specify a channel of interest, using multicast group and source addresses in its join request. Upon its reception, the upstream router that supports IGMPv3/MLDv2 establishes the shortest-path tree toward the source without coordinating a shared tree. This function is called the source-filtering function and is required to support Source-Specific Multicast (SSM) [3].

Recently, the Lightweight IGMPv3 (LW-IGMPv3) and Lightweight MLDv2 (LW-MLDv2) [4] protocols have been defined as the proposed standard protocols in the IETF. These protocols provide protocol simplicity for mobile hosts and routers, as they eliminate a complex state machine from the full versions of IGMPv3 and MLDv2 and promote the opportunity to implement SSM in mobile communications.

This document assumes that both multicast routers and mobile hosts are IGMPv3/MLDv2 capable, regardless of whether the protocols are the full or lightweight version. This document does not consider interoperability with older protocol versions. One of the reasons for this lack of interoperability with older IGMP/MLD protocols is that the explicit tracking function does not work properly with older IGMP/MLD protocols because of a report-suppression mechanism; a host would not send a pending IGMP/MLD Report if a similar report was sent by another listener on the link.

7. Security Considerations

This document neither provides new functions nor modifies the standard functions defined in [1], [2], and [4]. Therefore, no additional security considerations are provided.

8. Acknowledgements

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Appendix A. Unicasting a General Query

This appendix describes the possible IGMP and MLD protocol extensions for further optimization in mobile and wireless environments. It might be beneficial to include the following considerations when a newer version or modification of IGMP and MLD protocols is considered in the future.

IGMPv3 and MLDv2 specifications [1] [2] explain that a host must accept and process any query whose IP Destination Address field contains any of the addresses (unicast or multicast) assigned to the interface on which the query arrives. In general, the all-hosts multicast address (224.0.0.1) or link-scope all-nodes multicast address (ff02::1) is used as the IP destination address of an IGMP/MLD General Query. On the other hand, according to [1] and [2], a router may be able to unicast a General Query to the tracked member hosts in [Query Interval], if the router keeps track of membership information (Section 3).

Unicasting an IGMP/MLD General Query would reduce the drain on the battery power of mobile hosts, as only the active hosts that have been receiving multicast contents respond to the unicast IGMP/MLD General Query messages and non-active hosts do not need to pay attention to the IGMP/MLD Query messages. This also allows the upstream router to proceed with fast leaves (or shorten leave latency) by setting LMQC/LLQC smaller because, ideally, the router can immediately converge and update the membership information.

However, there is a concern regarding the unicast General Query: if a multicast router sends a General Query "only" by unicast, it cannot discover potential member hosts whose join requests were lost. Since the hosts do not retransmit the same join requests (i.e., unsolicited Report messages), they lose the chance to join the channels unless the upstream router asks for membership information by sending a multicast General Query. This concern will be solved by using both unicast and multicast General Queries and configuring the [Query Interval] timer value for multicast General Query and the [Unicast Query Interval] timer value for unicast General Query. However, using two different timers for General Queries would require a protocol extension that is beyond the scope of this document. If a router does not distinguish multicast and unicast General Query Intervals, the router should only use and enable multicast General Queries.

Also, the unicast General Query does not remove the need for the multicast General Query. The multicast General Query is necessary for updating membership information if the information is not correctly synchronized due to missing reports. Therefore, the unicast General Query should not be used for an implementation that does not allow the configuration of different query interval timers such as [Query Interval] and [Unicast Query Interval]. If a router does not distinguish these multicast and unicast General Query Intervals, the router should only use and enable multicast General Queries.

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