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Proposal for Tuning IGMPv3/MLDv2 Protocol Behavior in Wireless and
Mobile networks

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Abstract

This document proposes a variety of optimization approaches for tuning IGMPv3 and MLDv2 protocols. It aims to provide useful guideline to allow efficient multicast communication in wireless and mobile networks using the current IGMP/MLD protocols.

Conventions used in this document

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 RFC-2119 [RFC2119].

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1. Introduction

Multicasting is more efficient a method of supporting group communication than unicasting. With the wide deployment of different wireless networks, multicast communication over wireless network comes to attract more and more interests from content and service providers, but still faces great challenges when considering dynamic group membership and constant update of delivery path due to node movement, which is highly required in the wireless or mobile network. On the other hand, unlike wired network, some of wireless networks often offer limited reliability, consume more power and cost more transmission overhead, thus in worse case are more prone to loss and congestion.

Multicast network is generally constructed by IGMP/MLD group management protocol to track valid receivers and by multicast routing protocol to build multicast delivery paths. This document focuses only on IGMP/MLD protocols, which are used by a mobile user to subscribe a multicast group and are most possibly to be exposed to wireless link to support terminal mobility. As IGMP and MLD are designed for fixed users using wired link, they does not work perfectly for wireless link types. They should be enhanced or tuned to adapt to wireless and mobile environment to meet the reliability and efficiency requirements in the scenarios described in [REQUIRE][RFC 5757].

This memo proposes a variety of optimization approaches for tuning IGMP/MLD protocols in wireless or mobile communication environment. It aims to make the minimum tuning on the protocol behavior without introducing interoperability issues, and to improve the performance of wireless and mobile multicast networks. These solutions can also be used in wired network when efficiency and reliability are required. They are discussed in detail in Section 4.

2. Impact of wireless and mobility on IGMP/MLD

This section analyzes the impact of wireless or mobility on IGMP/MLD by comparing wireless multicast with wired multicast and comparing different wireless link models. It then gives the requirements of

wireless and mobile multicast on IGMP/MLD protocols according to the analysis.

2.1. Comparison analysis between wired and wireless multicast

Existing multicast support for fixed user can be extended to mobile users in wireless environments. However applying such support to wireless multicast is difficult for the following five reasons.

- O Limited Bandwidth: In contrast with wired link, wireless link usually has limited bandwidth. This situation will be made even worse if wireless link has to carry high volume video multicast data. Also the bandwidth available in upstream direction and downstream direction may not be equal.
- O Large packets Loss: In contrast with wired multicast, wireless multicast has packet loss that range between 1% and 30%, based on the links types and conditions. And when packets have to travel between home and access networks e.g. through tunnel, the packets are prone to be lost if the distance between the two networks is long.
- O Frequent Membership change: In fixed multicast, membership change only happens when a user leave or joins a group while in the mobile multicast, membership changes may also occur when a user changes its location.
- O Prone to performance degradation: Due to possible unwanted interaction of protocols across layers and user movement, the wireless network may be overwhelmed with more excessive traffic than wired network. In worse case, this may lead to network performance degrading and network connection complete loss.
- O Increased Leave Latency: Unlike fixed multicast, the leave latency in the mobile multicast will be increased due to user movement. And if the traffic has to be transmitted between access network and the home network, or if the handshake is required between these two networks, the Leave Latency will be increased further more.

Figure 1 shows the details for the difference between wired/fixed multicast and wireless/mobile multicast.

Issues	Wired or fixed Multicast	Wireless/mobile multicast
Bandwidth	Plentiful	Limited and variable possibly asymmetric
Loss of Packets	Infrequent(<1%)	Frequent and variable (1%-30% based on links)
Membership Changes	Only when a user leaves and joins a group	Also when a user moves to another location
Reliability	Possible use of a transport-layer protocol(such as the Multicast File Transfer Protocol)	More complex due to wireless links and user mobility; possible unwanted interaction of protocols at transport and link layers
Leave Latency	not changed by user movement	Increased due to user movement and lost packet

Figure 1. Comparison between wired/fixed multicast and wireless/mobile multicast

2.2. Link models analysis for wireless multicast

There are various types of wireless links, each with different feature and performance. In this document, we according to the transmission mode categorize the wireless link type into three typical link models:

- O Point To Point (PTP) link model
- O Point To Multipoint (PTMP) link model
- O Broadcast link model

PTP link model is the model with one dedicated link that connects exactly two communication facilities. For multicast transmission, each PTP link has only one receiver and the bandwidth is dedicated

for each receiver. Also one unique prefix or set of unique prefixes will be assigned to each receiver. Such link model can be accomplished by running PPP on the link or having separate VLAN for each receiver.

PTMP link model is the model with multipoint link which consists of a series of receivers and one centralized transmitter. Unlike P2P link model, PTMP provide downlink common channels and dedicated uplink channel for each user. Bandwidth and prefix in this model are shared by all the receivers on the same link. Therefore Duplicate Address Detection (DAD) should be performed to check whether the assigned address is used by other receivers.

Broadcast link model is the model with the link connecting two or more nodes and supporting broadcast transmission. Such link model is quite similar to fixed Ethernet link model and its link resource is shared in both uplink and downlink directions. The bandwidth and prefix are shared by all the receivers and DAD is required to avoid address collision.

Figure 2 shows the details for the difference between different wireless link models.

Features	PTP link model	PTMP link model	Broadcast link model
Shared link/ Dedicated link	Dedicated uplink and downlink channels for each user	Common downlink channels and dedicated uplink channels for each user	common downlink Channel for each user
Shared Prefix /Dedicated Prefix	Per Prefix for each receiver No need DAD	Prefix shared by all receivers DAD is required	Prefix shared by all receivers DAD is required
Shared Service Support	Not Support	Support	Support
link layer Broadcast Multicast Support	Only one node On the link Forward multicast packets to the only receiver on the link	Link Layer Multicast Support using Backend (e.g.,AR) IGMP/MLD Snooping at AR	Broadcast Support at L2 using switch IGMP/MLD Snooping at switch
Ethernet link Support	Not support	Not support	Ethernet Support By Implementing Bridge

Figure 2. Wireless Link Models Analysis

2.3. Requirements of wireless and mobile multicast on IGMP/MLD

Due to the characteristics of wireless and mobile multicast described in the 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 [REQUIRE]:

- o Adaptive to different link characteristics: IGMP and MLD are originally designed for wired multicast and some of their processing is not applicable to wireless multicast for its asymmetrical link, limited bandwidth, larger packet loss rate, increased leave latency, and etc. Also Wireless network has various link types, each of them has different bandwidth and performance. These require IGMP/MLD protocol behavior should be tuned to adapt to different link model and link conditions.
- o Minimal Join and Leave Latency: Fast join and leave of a subscriber helps to improve the user's experience during channel join and channel zapping. Fast leave also facilitates releasing of unused network resources quickly. Besides, mobility and handover may cause a user to join and leave a multicast group frequently, which also require fast join and leave to accelerate service activation and to optimize resource usages.
- o Robustness to packet loss: Wireless link has the characteristic that packet transmission is unreliable due to instable link conditions and limited bandwidth. For mobile IP network, packets sometimes have to travel between home network and foreign network and have the possibility of being lost due to long distance transmission. These network scenarios have more strict robustness requirement on delivery of IGMP and MLD protocol messages.
- o Minimum packet transmission: Wireless link resources are usually more precious and limited compared to their wired counterpart, and are prone to be congested when carrying high volume multicast stream. Minimizing packet exchange without degrading general protocol performance should also be emphasized to improve efficiency and make good use of network capacity and processing capability.
- o Avoiding packet burst: Large number of packets generated within a short time interval may have the tendency to deteriorate wireless network conditions. IGMP and MLD when using in wireless and mobile networks should be optimized if their protocol message generation has the potential of introducing packet burst.

According to these requirements, in the following parts of the document, current versions of IGMP/MLD protocols are evaluated whether their various protocol aspects are applicable to wireless and mobile multicast communications. They will be optimized to meet these requirements without new features introduced on the wire or link, without new message type defined, and without interoperability issues introduced, which is referred to as "tuning" of IGMP/MLD protocols.

3. Evaluation of IGMP/MLD on wireless and mobile multicast

This section analyzes the applicability of IGMP and MLD to wireless communication in the following aspects:

- O General evaluation of different versions: IGMPv2 [RFC2236] and MLDv1 [RFC2710] only support ASM communication mode. They do not support SSM subscription and explicit tracking. IGMPv3 [RFC3376] and MLDv2 [RFC3810] and their lightweight version LW-IGMPv3/LW-MLDv2 [RFC5760] support all the features of ASM/SSM communication modes and explicit tracking. Because SSM is more efficient and secure than ASM for IPTV application, and explicit tracking enables faster channel zapping and better manageability capability, IGMPv3/MLDv2 and LW-IGMPv3/MLDv2 are more promising to be deployed widely than IGMPv2 and MLDv1.
- O Robustness: IGMP/MLD actively sends unsolicited Report or Leave message to join or leave a group, and solicited Report to respond to Queries. Unsolicited Report and Leave messages are more important for ensuring satisfactory user experience and should be guaranteed to improve service performance. Current IGMP and MLD provide the reliability for these messages by non responsive retransmission, which is not adequate from both the robustness and efficiency aspects when they are used on unreliable wireless link or have to be exchanged over the tunnel between home network and access network separated by long distance [ROBUST][ACK]. For IGMPv3/MLDv2, because unsolicited report and leave messages will not be suppressed by report from other host, it is possible to adopt acknowledgement-retransmission to improve reliability and reduce superfluous packet transmission [IGMP-ACK].

Besides, for IGMPv3/MLDv2, because the router could by explicit tracking establishes membership database recording each valid receiver, it is possible to deduce the possible loss of some protocol messages according to the feedback after their transmission, and to take some remedies (e.g. by retransmission)

to enable more reliable transmission of these messages in bad conditions.

- O Efficiency: IGMPv2 and MLDv1 use host suppression to suppress duplicated membership reports on the link. In IGMPv3 and MLDv2, because host suppression is not adopted, the report count will be numerous if the number of valid receivers on the network is large. IGMPv3 and MLDv2 should be optimized to try to minimize unnecessary packet transmission to compensate this drawback. As an example, because an IGMPv3/MLDv2 router has record of each user in its state database by explicit tracking, it is possible to eliminate the need for query timeouts when receiving leave messages and to improve the efficiency by reducing both the unnecessary Queries and reports generated on a network.

And as described in [REQUIRE] and [RFC5757], the default timer values and counter values specified in IGMP and MLD were not designed for the mobility context. This may result in a slow reaction following a client join or leave, in possible packet loss under worse conditions, or in overburdening the wireless link by excessive packets exchange than necessary. These issues can be addressed by tuning these parameters for the expected packet loss on a link to optimize service performance and resource usage.

The comparison between IGMPv2/MLDv1 and IGMPv3/MLDv2 is illustrated in figure 3. In summary, it is desirable to choose IGMPv3/MLDv2 or LW-IGMPv3/MLDv2 as the group management protocol for wireless or mobile multicast. They should be optimized to adapt to wireless and mobile networks to meet the efficiency and reliability requirement for these networks. These optimizations range from the tuning of the parameters (e.g. the Query Interval and other variables), to the tuning of protocol behavior without introducing interoperability issues. Considering an enhancement in one direction might introduce side effects in another one, balances should be taken carefully to avoid defects and improve protocol performance as a whole.

Issues	IGMPv2/MLDv1	IGMPv3/MLDv2
Default Timer and Robustness Variable	Not designed for Mobility context Need to be tuned	Not designed for Mobility context Need to be tuned
Explicit Tracking	Not Support	Support
ASM and SSM Subscription	Only Support ASM Subscription	Both Support
Explicit Join and Leave	Support	Support
Host Suppression	Support	Not Support

Figure 3. Comparison between IGMPv2/MLDv1 and IGMPv3/MLDv2

4. IGMP/MLD tuning optimization for Wireless or Mobile Network

As mentioned in section 2, IGMPv3/MLDv2 or LW-IGMPv3/MLDv2 is recommended to be used as the basis for optimization of IGMP/MLD to adapt to wireless and mobile networks. In this section, taking these characteristics requirement into account, we will discuss several optimization approaches for tuning of IGMPv3 and MLDv2 in wireless environment. The optimizations try to minimize the packet transmission for both the Reports and Queries, and at the meanwhile take the factor of improving reliability into account, with minimum cost. Different link types are also considered for the tuning behavior.

4.1. Explicit Tracking and Query Suppression

In IGMPv2/MLDv1, the member reports are suppressed if the same report has already been sent by another host in the network which is also referred to as host suppression. As described in the A.2 of [RFC3810], the suppression of multicast listener reports has been removed in MLDv2 due to the following reasons:

- Routers may want to track per-host multicast listener status on an interface. This enables the router to track each individual host that is joined to a particular group or channel and allow minimal leave latencies when a host leaves a multicast group or channel.
- Multicast Listener Report suppression does not work well on bridged LANs. Many bridges and Layer2/Layer3 switches that implement MLD snooping do not forward MLD messages across LAN segments in order to prevent multicast listener report suppression.
- By eliminating multicast listener report suppression, hosts have fewer messages to process; this leads to a simpler state machine implementation.
- In MLDv2, a single multicast listener report now bundles multiple multicast address records to decrease the number of packets sent. In comparison, the previous version of MLD required that each multicast address be reported in a separate message.

Without host suppression, it is possible to enable explicit tracking on a router by which the local replication can be used by the router to inspect incoming join and leave requests, record or refresh the membership state for each host on the interface, and take appropriate action to each received report. In the meanwhile, the router builds a table to track which channel being forwarded to each port. If the channel being requested to view is already being received at the router, it can replicate the stream and forward to this new requester which ensure good response time.

By using the tracking table mentioned above, the router has the capability to learn if a particular multicast address has any members on an attached link or if any of the sources from the specified list for the particular multicast address has any members on an attached link or not. Such capability makes Group specific Query or Source-and-Group Specific Queries, which are sent to query other members when a member leaves, unnecessary to be used because the router has already known who are active on the interface using explicit tracking. Therefore it is desirable that these two Queries are eliminated when explicit tracking is used. But General periodical Query by a router to solicit current state reports to refresh existing membership state database should still be used to prevent incorrectness of the database due to the possible loss of explicit join and leave message in some cases.

The main benefits of using explicit tracking without Group specific Query or Source-and-Group Specific Queries are that it provides:

- O minimizing packet number and packet burst: Elimination of Group and Source-Group specific Queries when a member leaves a group will reduce the number of transmitted Group Specific Queries. And finally the total number of Reports in response to Group Specific Queries can be drastically reduced.
- O Minimal leave latencies: an IGMPv3/MLDv2 router configured with explicit tracking can immediately stop forwarding traffic if the last host to request to receive traffic from the router indicates its leave from the group.
- O Faster channel changing: The channel change time of the receiver application depends on the leave latency, that is to say, single host can not receive the new multicast stream before forwarding of the old stream has stopped.
- O Reducing Power consumption: Due to elimination of the suppression of membership reports, the host does not need to spend processing power to hear and determine if the same report has already been sent by another host in the network, which is beneficial to mobile hosts that do not have enough battery power.

4.2. Report Suppression for the hosts

The large number of Reports and bad link condition may result in packets burst. This packet burst can be mitigated by having the router aggregate the responses (membership reports) from multiple clients. The router can intercept IGMP/MLD reports coming from hosts, and forwards a summarized version to the upstream router only when necessary. Typically this means that the router will forward IGMP/MLD membership reports as follows:

- Unsolicited membership reports (channel change requests) are forwarded only when the first subscriber joins a multicast group, or the last subscriber leaves a multicast group. This tells the upstream router to begin or stop sending this channel to this router.
- Solicited membership reports (sent in response to a query) are forwarded once per multicast group. The router may also aggregate multiple responses together into a single membership report.

4.3. Query Suppression for the routers

The large number of Queries and bad link condition may result in packets burst. This packet burst can be mitigated by having the downstream router stop forwarding IGMP/MLD Queries packets sent to

the hosts and respond with report as proxy to the upstream router. Typically this means that the router will:

- Never send a specific query to any client, and
- Send general queries only to those clients receiving at least one multicast group

4.4. Minimizing Query Frequency by increasing interval each time

In IGMPv3/MLDv2, Group Specific Queries and Source and Group specific Queries are sent for [Last Member Query Count] times with short fixed [Last Member Query Interval], to learn whether there are valid members from an attached link. If the network is undergoing congestion, the multiple transmissions of the queries may further deteriorate the bad conditions. To eliminate the bad effects for this, these Queries can be slowed down when a router can not collect successfully expected members' report responses in the mean while it detects the network congestion is going to happen. The slowing down process of the Queries could be arranged in a prolonged time interval as described in [ADAPTIVE].

The slow down behavior is: a router after sending a Query, if acquires the expected responses from the receivers, refreshes its state database and stop the querying retransmission process, or if after a time interval fails to get the expected report responses, resends a Query with an increased (e.g. double) interval. This process can be repeated, for each time the retransmission is arranged in a prolonged time interval, till the router receives the expected responses, or determines the receiver is unreachable and then stops the sending of the Query ultimately. The router can make judgment on not getting expected response from the Queries in the following cases:

- O When Group Specific Query and Source and Group Specific Queries are used to track other numbers, the router can not collect any response from the link.
- O When all group members leave the group or move out of scope, the General Query sent by the router can not solicit any responses from the link, as mentioned in section 4.9.
- O When General Query is retransmitted due to possible loss deducing from no responses from valid members in the database.

- O When General Query is retransmitted by a router on startup [RFC3376][RFC3810], it gets no membership response from the interface.
- O When unicast Query is sent to solicit a particular receiver, if the router can not get responses from the receiver, as described in section 4.5 and 4.6.

In the above cases, if the router fails to get expected response from the network, and if the link condition is bad or in congestion, the router could retransmit the Queries in increased interval. This query retransmission with incremental interval enables the router to reduce the total packet retransmission times in the same time period comparing with retransmission for multiple times with fixed interval, and at the mean time gain some degree of reliability. The variable time interval and the termination condition should be configurable and could be set according to actual network condition, which is out the scope of this document.

4.5. Switching Between Unicast Query and Multicast Query

IGMP/MLD protocols define the use of multicast Queries whose destination addresses are multicast addresses and also allow use of unicast Queries with unicast destination. The unicast Query is sent only for one destination and has the advantages of not affecting other host on the same link. This is especially desirable for wireless communication because the mobile terminal often has limited battery power. But if the number of valid receivers is large, using unicast Query instead of multicast Query will introduce large number of Queries because each Query will be generated for each member, which will not be an efficient use of link resources. In this case the normal multicast Query will be a good choice because only one Query needs to be sent. On the other hand of the number of receivers to be queried is small, the unicast Query is advantageous over multicast one.

The router can choose to switch between unicast and multicast Query according to the practical network conditions. For example, if the receiver number is small, the router could send unicast Queries respectively to each receiver to solicit their membership states, without arousing other host which is in the dormant state. When the receiver number reaches a predefined level, the router could change to use multicast Queries. The router could make the switching flexibly according to practical conditions to improve the efficiency.

4.6. Using General Query with Unicast Query

Unicast Query also can be used in addition to General Query to improve the robustness of solicited reports when General Query fails to collect its valid members. It requires the explicit tracking to be enabled on the router. Its basic behavior is: a router after sending a periodical Query collects successfully all the members' report responses except for one or two which are currently still valid in its database. This may be because the non-respondent ones silently leave the network without any notification, or because their reports are lost due to some unknown reason. The router in this case could choose to unicast a Query respectively to each non-respondent 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 for [Last Member Query Count] times, following the same rule of [3376] or [3810], or could be resent in incremental interval, as described in section 4.4.

4.7. Retransmission of General Queries

In IGMPv3 and MLDv2, apart from the continuously periodical transmission, General Query is also transmitted during a router's startup. It will be transmitted for [Startup Query Count] times with [Startup Query Interval], to improve reliability of General Query during startup. There are some other cases where retransmission of General Query is beneficial which are not covered by current IGMPv3/MLDv2 protocols as shown in the following.

For example, a router which keeps track of all its active receivers, if after sending a General Query, may fail to get any response from the receivers which are still valid in its membership database. This may be because all the valid receivers leaves the groups or moves out of the range of the link at the moment, or because all the responses of the receivers are lost, or because the sent Query does not arrive at the other side of the link. If current database indicates the number of the valid receiver is not small, the router could choose to compensate this situation by retransmitting the General Query to solicit its active members.

This compensating General Query could be sent several times, if the router can not get any feedback from the receivers which are previous in the database. The repetition of the transmission could in fixed

interval such as [Last Member Query Interval], or could in prolonged interval if the link condition is not good.

4.8. General Query Suppression with no receiver

In IGMPv3 and MLDv2, General Query is multicast sent periodically and continuously without any limitations. It helps solicit the state of current valid member but has influence on all terminals, whether they are valid multicast receivers or not. When there is no receiver on the link, the transmission of the General Query is a waste of resources for both terminals and the router.

The IGMPv3/MLDv2 router could suppress its transmission of General Query if there is no valid multicast receiver on the link, e.g. in the following cases:

- O If 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 sending Group and Source Group Specific Queries;
- O If the only member on a PTP link reports its leaving;
- O If the router after retransmission of General Queries on startup fails to get any response from any member;
- O If the router previously has valid members but fails to get any response from any member after several rounds of General Queries or Unicast Queries;

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

4.9. Tuning Response Delay according to link type and status

IGMPv3 and MLDv2 use delayed response mechanism to spread Report messages from different hosts over a longer interval which can greatly reduce possibility of packet burstiness. This is implemented by the host responding to a Query in a specific time randomly chosen between 0 and [Maximum Response Delay]. The value of [Maximum Response Delay] parameter is determined by the router and is carried

in Query messages to inform the valid hosts to make the selection. A long delay will lessen the burstiness but will increase leave latency (the time between when the last listener stops listening to a source or multicast address and when the traffic stops flowing).

In order to avoid burstiness of MLD messages and reduce leave latency, explicit tracking with Group Specific Query eliminated is recommended to be used first to reduce leave latency. Then the Response Delay may be dynamically calculated based on the expected number of Reporters for each Query and link type and link status.

- o If the expected number of Reporters is large and link condition is bad, the system administrator MUST choose the longer Maximum Response Delay; if the expected number of Reporters is small and the link condition is good, the administrator may choose the smaller Maximum response Delay. In this case, the IGMP/MLD packet burstiness can be reduced.
- o Another case is if the link type is PTP which means the resource is dedicated for one receiver on each link, then the Maximum Response Delay can be chosen smaller, if the link type is shared medium link or P2MP, then the Maximum Response Delay can be configured larger.

The Maximum Response Delay can be configured by the administrator as mentioned above, or be calculated automatically by software tool implemented according to experiential model on different link modes. As the router arrives at a value appropriate for current link type and conditions, it will encode the value in Query messages to inform the host to make the response. The determination of the instant Maximum Response Delay value is out of this document's scope.

4.10. Triggering reports and queries quickly during handover

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

For the access router, it could trigger a Query to the terminal as soon as it detects a new terminal on its link. This could be a General Query if the router does not know whether or not the terminal is a valid receiver or if the number of the entering terminals is not small. Or this Query could also be a unicast Query

for only a small quantity of terminals to prevent unnecessary action of other terminals in the switching area.

For the terminal, it could trigger a report if it is currently in the multicast reception state. This helps establish more quickly the membership states and enable faster multicast stream injection because active report from the host does not requires the router to wait for the query-response round in the passive reporting cases.

5. Security Considerations

They will be described in the later version of this draft.

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