

Enhanced Efficiency of Mapping Distribution Protocols in Scalable Routing and Addressing Architectures

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Abstract—In this paper, we present a discussion of some architectural principles pertaining to mapping distribution protocols that are common components of proposed designs to improve the scalability of future Internet routing tables. The efficiency of a mapping distribution protocol in terms of response time and the volume of traffic load it generates are important considerations. We consider how Egress Tunnel Routers (ETRs) can perform aggregation of end-point ID (EID) address space belonging to their downstream delivery networks, in spite of migration/re-homing of some subprefixes to other ETRs. This aggregation may be useful for reducing the processing load and memory consumption associated with mapping messages, especially in resource-constrained components of the mapping distribution system. Consequently, the proposed methods can also help improve response time (e.g., first packet delay). Some key architectural issues, their potential solutions and trade-offs are discussed. The overarching goal is to expose and discuss some subtleties in design considerations for mapping distribution and management.

Index Terms—Future Internet Architecture, Scalable Internet, Scalable Routing and Addressing, Mapping Distribution Protocol, Locator and ID Separation, LISP, Aggregation

I. INTRODUCTION

The problem of scalability of today’s Internet routing system has been discussed in recent Internet Engineering Task Force (IETF) reports[1][2]. Several proposals aimed at solving this problem are under study in Internet Research Task Force’s (IRTF’s) Routing Research Group (RRG)[3]-[11]. In this paper, we present some architectural principles pertaining to the mapping distribution protocols (MDPs) [9]-[11], especially applicable to the so-called “map-and-encap” class of solutions. Aforementioned architectural principles enhance the efficiency of MDPs in terms of (1) Better utilization of resources (e.g., processing and memory) at Ingress Tunnel Routers (ITRs) and mapping servers, and consequently, (2) Reduction of mapping system response time (e.g., first packet delay). We consider how Egress Tunnel Routers (ETRs) can perform aggregation of end-point ID (EID) address space belonging to their downstream delivery networks, in spite of migration/re-homing of some subprefixes to other ETRs. We discuss incorporation of an exception notification as part of the map response message to indicate that portions of the ID space (some small number of more specific prefixes or subprefixes) under a less

specific prefix have moved to or reside at different ETRs. This aggregation may be useful for reducing the processing load and memory consumption associated with map messages, especially at resource-constrained ITRs and subsystems of the mapping distribution system. We also consider another architectural concept where the ETRs are organized in a hierarchical manner for the potential benefit of aggregation of their EID address spaces. The aforesaid architectural principles are described and discussed in detail in Sections III and IV. Conclusions and possible directions for extending this study are stated in Section V.

II. ARCHITECTURAL FRAMEWORK FOR ID TO LOCATOR MAPPING

We feel that the architectural principles examined here are generally applicable to several of the proposals being discussed in the RRG (summarized in [3]), and their associated mapping distribution protocols. An example of map-and-encap solutions is the Locator ID Separation Protocol (LISP) protocol[4], and here we use LISP-like high level architecture to describe our proposal for enhancing the efficiency of mapping distribution and management. The specific MDP associated with LISP is known as LISP+ALT[9]. To assist in this discussion, we start with the high level architecture of a map-and-encap approach as illustrated in Fig. 1. This helps anchor the discussion of the principles of the mapping distribution protocol to an architectural framework; the specific architecture can, however, vary and the ideas presented here are generally relevant to any of the proposals that are currently being reviewed in RRG. As shown in Fig. 1, the Egress Tunnel Routers (ETRs) generate map messages to inform the ID-Locator Mapping (ILM) servers of end-point ID prefixes or delivery-network address ranges that can be reached through them. The ILMs are repositories for complete mapping information, while the ILM-Regional (ILM-R) servers can contain partial and/or regionally relevant mapping information. The ETRs can “push” ID-to-locator mapping information pertaining to the delivery networks under their purview to an ILM-R or an ILM they are associated with. The ILM-Rs push the mapping information received from ETRs to the ILMs, and the ILMs update each other by pushing the mapping updates as they are received. When an Ingress

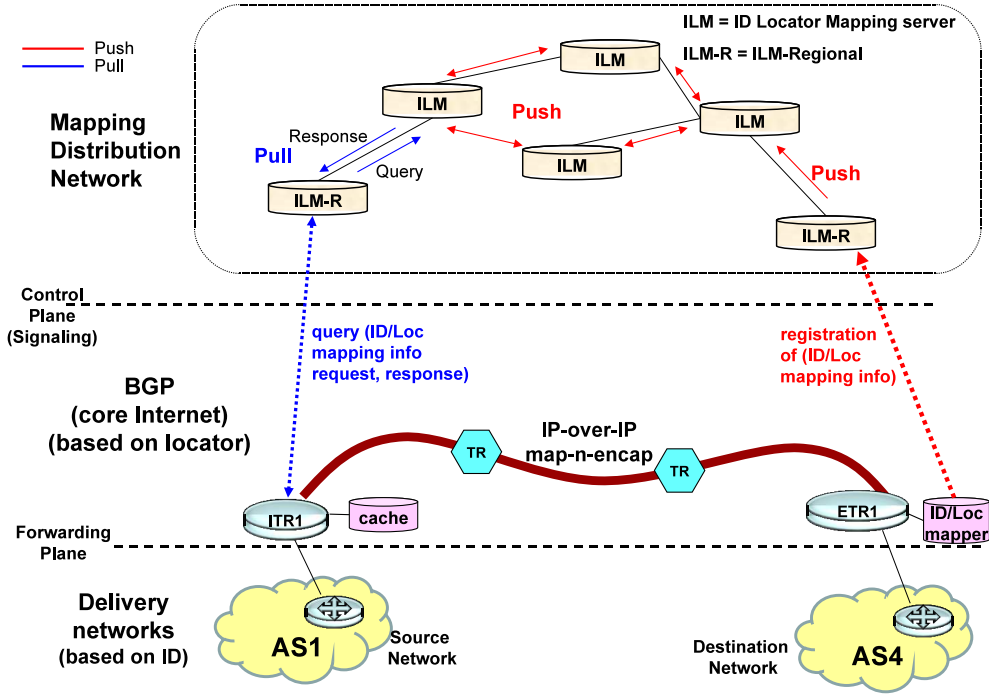


Fig. 1. An example of map-and-encap and mapping distribution architecture.

Tunnel Router (ITR) does not have mapping information for an EID, it initiates “pull” requests (query/response) to the ILM-R that it has access to. The ILM-R can then pull the relevant mapping information from an ILM (if necessary) and respond back to the ITR.

III. MAPPING DISTRIBUTION OF SUBPREFIXES SPREAD ACROSS MULTIPLE ETRs

With the help of Fig. 2, it is illustrated that while a large endpoint address space contained in a prefix may be mostly associated with the delivery networks served by a single ETR, some fragments (subprefixes) of that address space may be located elsewhere at different ETRs. Let $a/20$ denote an address block with prefix-length 20 that is conceptually viewed as composed of 16 subprefixes of size $/24$ that are denoted as $a_0/24, a_1/24, \dots, a_{15}/24$. In Fig. 2, for example, most of the sub-blocks of addresses in $a/20$ are at ETR1, while only two of its subprefixes $a_7/24$ and $a_{14}/24$ are elsewhere, at ETR3 and ETR2, respectively. From the point of view of efficiency of the mapping distribution protocol, it may be beneficial for ETR1 to announce a map for the entire space $a/20$ (rather than fragment it into a multitude of more-specific prefixes), and provide the necessary exceptions in the map information. Thus a map announcement from ETR1 could be in the form of *Map:($a/20, ETR1$; Exceptions: $a_7/24, a_{14}/24$)*. In addition, ETR2 and ETR3 announce the maps for $a_{14}/24$ and $a_7/24$ respectively, and so the ILMs know where the exception endpoint ID addresses are located. The details of how the map responses are structured and communicated will be described shortly.

To support the above assertions with numerical data, we provide an actual example and some statistics regarding holes

in prefixes based on Internet Corporation for Assigned Names and Numbers (ICANN) reports [12] and Routeviews trace data [13]. From ICANN BGP reports [12], we observe, as an example, that prefixes 129.6.0.0/17 and 129.6.0.128/17 are originated from AS49, and additionally 129.6.112.0/24 is originated from AS10886. Thus we notice that there is a prefix-hole (or exception) in that 129.6.112.0/24 is originated from AS10886, while the rest of the prefix 129.6.0.0/17 (in fact the rest of 129.6.0.0/16) is originated from AS49. Fig. 3 illustrates how this kind of prefix-hole results in a substantial increase in number of EID-to-locator map entries for map-and-encap schemes. In Fig. 4, measurements based on Routeviews trace data [13] are reported with a plot of the number of prefix-holes vs. the corresponding mask-length. The y-axis in Fig. 4 is essentially the number of subprefixes of length x (x being value on the x-axis) such that each has at least one less-specific announced with a different origin AS as compared to that of the subprefix. Many of these situations, if not all, would result in holes in the EID-to-locator maps. The trace data used in Fig. 4 consisted of 304,723 Routing Information Base (RIB) entries from which a total of 60,988 were identified as likely prefix-holes. Based on this type of empirical evidence, we feel that there is a strong need to address the map-proliferation problem with suitable enhancements to the mapping distribution protocol.

Now the interesting question is in what ways does the mapping distribution system communicate mapping information to the ITRs while coping with EID prefix-holes (or exceptions)? This issue is illustrated in the lower left-hand portion of Fig. 2. The sending host initiates a packet destined for an address a_6^1 , which is in $a_6/24$ and hence in the normal portion of $a/20$

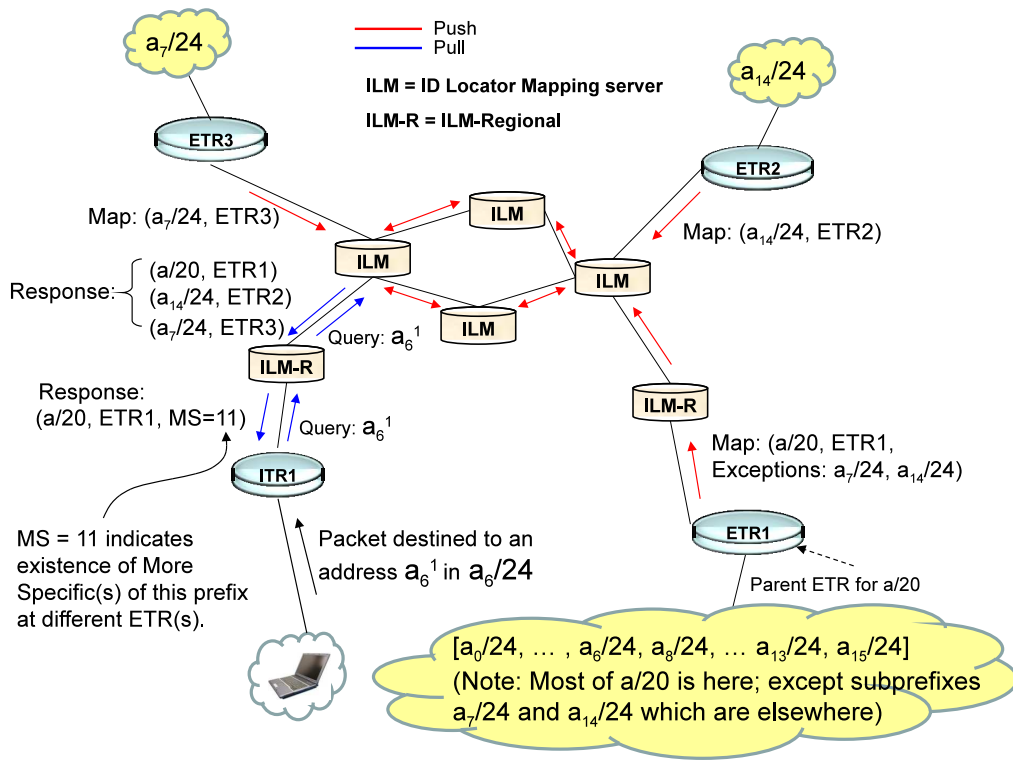


Fig. 2. Illustration of endpoint ID aggregation and exception concepts.

Aggregate: 129.6.0.0/16	
Announced in BGP-4:	
129.6.0.0/17	Origin: AS49
129.6.0.128/17	Origin: AS49
129.6.112.0/24	Origin: AS10886
EID to Locator (ETR) Mapping:	
EID:	ETR (equivalent)
129.6.0.0/18	ETR49
129.6.64.0/19	ETR49
129.6.96.0/20	ETR49
129.6.112.0/24	ETR10886
129.6.113.0/24	ETR49
129.6.114.0/23	ETR49
129.6.116.0/22	ETR49
129.6.120.0/21	ETR49
129.6.128.0/17	ETR49

Fig. 3. Impact of a prefix-hole on multiplication of EID-to-locator map entries.

and not in the exception portion. In this case, we assume that the ITR1 does not have the map information, so it sends a map request to its ILM-R. Assuming that the ILM-R does not have the map information either, it will send a map request to an ILM to which it is connected. The ILM can then send a response to the ILM-R, and this response can contain the information regarding matching prefix ($a/20$, ETR1) as well as the maps for the exceptions or the subprefixes that are elsewhere, namely, ($a_{14}/24$, ETR2) and ($a_7/24$, ETR3). Now a question arises as to which of the following approaches would

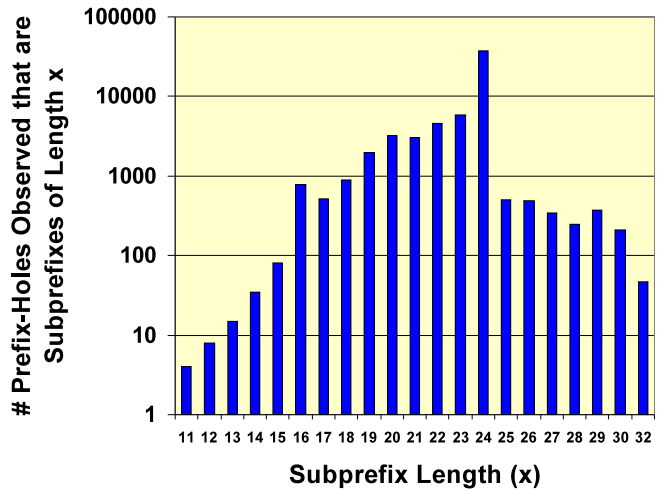


Fig. 4. Measurement of numbers of prefix-holes of various mask-lengths (from Routeviews trace data).

be the best choice:

- 1) ILM-R provides the complete mapping information for $a/20$ to ITR1 including all the maps for the relevant exception subprefixes.
- 2) ILM-R provides only the directly relevant map to ITR1 which in this case is ($a/20$, ETR1) and indicates that there are exceptions.
- 3) The mapping information transaction between ILM-R and ITR1 can dynamically use approach 1 or approach

2 above depending on the context (further explanation of this is provided below).

In the first approach, the advantage is that ITR1 would have the complete mapping for $a/20$ (including exception subprefixes), and it would not have to generate queries for subsequent first packets that are destined to any address in $a/20$, including $a_7/24$ and $a_{14}/24$. This would be true as long as ITR1 holds the received mapping information in its memory. However, the disadvantage is that if there is a significant number of exception subprefixes (in the example in consideration there are only two but in general it can be many more), then the very first packet destined for $a/20$ will experience a long delay, and also the processors at ITR1 and ILM-R can experience overload. In addition, the memory usage at ITR1 can be very inefficient as well.

The advantage of the second approach above is that the ILM-R does not overload resources at the ITR both in terms of processing and memory usage. This will help avoid resource exhaustion at the ITRs and thus provide better response time in handing mapping queries for the packets received from hosts. However, some care must be exercised here. ITR1 might save the mapping information for $a/20$ and reuse it. So it should be at least made aware that possibly there are subprefixes under $a/20$ that are at other ETRs. This can be taken care of by incorporating a More Specific (MS) indicator in the map response sent to ITR1 as shown in Fig. 2. This map response is of the form *Map:(a/20, ETR1, MS=11)*. The MS indicator is set to a binary value 11 to indicate to ITR1 that not all addresses in $a/20$ map to ETR1, and accordingly ITR1 will re-enquire next time there is a packet destined for a different address in $a/20$. One can go into the details of this methodology and improve it further; the detailed algorithm is described in Subsection III-A. The key idea here is that aggregation is beneficial, and subprefix exceptions must be handled with additional messages or indicators in the map.

The third approach above seeks adaptability to use either the first approach or the second depending on the context. Here a threshold (or limiting value), say H , can be applied to the number of map responses (map for the parent prefix plus all maps for the relevant exceptions subprefixes). If H is not exceeded, then the first approach would be used, else, the second approach would be used. This parameter can also be tuned administratively or dynamically (depending on the state in terms of resource availability at the ILM and/or the ITR). Above was a conceptual exposure to ways to handle exception notifications; we now proceed to formally describe the algorithm in detail.

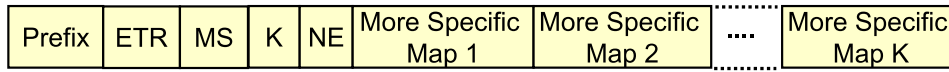
A. Details of the Map Response Algorithm

In Fig. 5, a candidate format is illustrated for the map response sent to an ITR. The More Specific (MS) indicator is a two-bit field, and is used to specify that there are additional maps available for more specific exception prefixes; the exact details of usage of the MS field will be described shortly. The number of additional more specific maps that would be included (in addition to the map for the less specific or

aggregate) is denoted by the variable K . The map message also carries information regarding the total number of holes or exceptions (NE). In general, $K \leq NE$, and that just means that the number of maps being communicated may be less than the actual number of exceptions or prefix holes. The message further contains (see Fig. 5) K maps for the more specifics. These maps are commonly a pairing of a more specific prefix with an associated ETR. But sometimes the ETR field may simply contain a value “Re-request” that indicates to the ITR that a fresh map request must be sent for addresses within that more specific prefix; the applicability of this will be explained below.

The details of map response generation algorithm can be described by explaining the usage of the format parameters that are shown in Fig. 5. The usage and interpretation of these parameters, namely MS, K and NE, are explained in Table I. There are four cases the algorithm should encompass as enumerated below (also refer to Table I).

- 1) **There is only one unique map response:** In responses to the map request, the ILM has only one unique {prefix, ETR} mapping response. There are no exception subprefixes in this case. The parameters in the map response are set to: MS = 00, $K = 0$, and NE = 0.
- 2) **All available exception maps are communicated:** In response to a map request, the ILM has multiple {prefix, ETR} mapping responses to notify the ITR, which include the immediately usable {prefix, ETR} mapping as well as mappings for all exception subprefixes. The parameters in the map response are set to: MS = 01 and $K = k$, where k is the # exception subprefixes whose maps are included. Further, the values of K and NE would be equal in this case. This case is one where the total number of exceptions or holes is relatively small, and hence it is possible to communicate all of them to the ITR without overloading the resources at the ITR or ILM-R.
- 3) **Subnets are further split into micro-subnets (mobile devices homed to different ETRs):** This is similar to Case 2 above, but here the ETR information for one or more of these subnets (i.e., exceptions) is denoted as “Re-request” in the map responses. This is because the specific subnet is further split, i.e., many micro-subnets exist with different ETRs. The micro-subnets may be mobile devices homed to different ETRs. There would be too many of these to report as exceptions in the map response. Hence, the map-response for an address in those micro-subnets warrants sending a fresh map request from the ITR. Then the ILM would respond back with a map specific to the micro-subnet or even the individual address (of a mobile device). So the map for the prefix or subnet from which the micro-subnets (or mobile addresses) are derived simply shows “Re-request” in the ETR field. In this case, the parameters in the map response are set to: MS = 10 and $K = k$, where k is the # exception subprefixes whose maps are included. Note that the number of exceptions (NE)



MS = More Specific indicator, K = # Maps to follow, NE = Number of Exceptions ($NE \geq K$)

Fig. 5. Illustration of a format for map response.

TABLE I
PARAMETERS AND THEIR INTERPRETATION IN THE MAP RESPONSE ALGORITHM

Case #	More Specific Indicator (MS)	# Exception Maps Included (K)	Total # Exceptions (NE)	Interpretation
Case 1	00	0	0	Map response has no exceptions.
Case 2	01	k	$n_e = k$	Map response has exceptions; All k map responses for the exception subnets are included.
Case 3	10	k	$n_e = k$	Map response has exceptions; All k map responses for the exception subnets are included but the ETR information for one or more specific subnets is "Re-request"; Subnets are further split into micro-subnets (e.g., mobile devices homed to different ETRs)
Case 4	11	k ($k < n_e$)	n_e	Map response has exceptions; # Exceptions exceeds threshold (H); Only a subset of exception maps is included; Maps for prioritized (frequently requested) subset of more specifics are included.

here is interpreted to include all exceptions but none of the ones that we referred to above as "micro-subnets". Naturally, the immediate parent subnet (with ETR shown as "Re-request") of a set of micro-subnets would be counted in the NE. Thus, the values of K and NE would be equal in this case also.

The usage scenario for this case can be further explained with an example. Consider a scenario when a /24 subprefix is split from a corporate /20 prefix and the company's mobile devices are allocated IP addresses from that one /24. The /20 is homed to ETR1 (except the /24) while the mobile devices are homed to many different ETRs elsewhere. The traffic from the ITR is almost entirely destined for addresses in the /20 other than the mobile-designated /24 part. So the ITR benefits by knowing that if it ever has traffic for an address in the mobile-designated /24, then it needs to re-request. Hence, the ITR having knowledge of just the exception subprefix - without knowing about its ETR - works quite efficiently as long as a majority of the traffic is destined for other addresses in the /20, and re-requests take care of fetching maps for the mobiles as needed.

4) **Partial set of exception maps are communicated:**

There would be situations when the number of maps for exceptions (or holes) may be quite large. There would be a threshold H, and if the total number of exceptions exceeds this threshold, then this (Case 4) approach will be used instead of that of Case 2 or Case 3. In such situations, a partial set of exception maps can be communicated to reduce the processing and/or memory burden on the ITR. In order to do this, a prioritized list of exceptions or more specifics may be maintained. The prioritization may be done possibly in accordance with an estimated frequency of map requests for addresses in those exception subprefixes. In this case, the map response would contain the main (less specific prefix) and a subset of maps for the more specifics based on priority. One additional difference relative to Cases 2 and

3 above would be that at least one (perhaps a few) of the more specific maps may show more specific prefixes that home to the same ETR as the aggregate less specific (i.e., parent) prefix. The reason for this will be clear in the use case scenario provided below. The remaining exception maps will contain other prioritized more specific prefixes which home to other ETRs (different from that of the parent prefix). In this case (i.e., Case 4), the parameters in the map response are set to: MS = 11, K = k , where k is the # exception subprefixes whose maps are included, and NE = n_e , where NE is a count of the total number of exceptions. (Refer to Case 3 for how NE is counted in case there is a subnet with many micro-subnets.) When $k < n_e$, there is a specific use for NE, and that can be explained as follows. The ITR would likely send additional map requests over a period of time after it has sent the first request that fetched a map response with MS=11 (i.e., with partial set of exception maps). It saves the maps for the aggregate prefix as well all other more specific prefixes. If at some point, the total number of maps with ETRs that are different from that of the parent prefix equals n_e (i.e., value of the NE parameter), then the ITR knows that it has received all exception maps. At this point, the ITR can discard from its memory the more specifics that have the same ETR as the parent prefix, and then the maps at the ITR will be complete and compact for the parent prefix and all its exceptions.

The usefulness of this case can be explained with an example scenario. Consider a scenario when Org-A has a /16 prefix; the bulk of it resides at the headquarters (ETR1); twelve /24s subprefixes (within the /16 prefix) are homed to other ETRs elsewhere; majority of the traffic for the /16 is destined to a smaller set of specific subnets with maps ($a_2/24$, ETR1), ($a_5/24$, ETR1), ($a_7/24$, ETR2), and ($a_{12}/24$, ETR3). Let us say these maps are also in the order of highest to lowest estimated frequency of map requests. In this case, the actual

number of exceptions is $n_e = 12$. Let us say, $H = 4$. Then, all 12 exception maps will not be communicated in one map response. The map response to an initial map request for an address in $a_2/24$ will fetch the maps $\{(a/16, \text{ETR1}), (a_2/24, \text{ETR1}), (a_5/24, \text{ETR1}), (a_7/24, \text{ETR2}), (a_{12}/24, \text{ETR3})\}$. Note that the first three maps all home to the same ETR1; the first one is for the parent (aggregate) prefix, and second and third are for two more specific /24s. The ITR will save this set of maps; it has only 2 of the 12 exception maps so far. The ITR may not make any other requests for a very long time since the majority of the traffic goes to the more specific prefixes for which the maps already exist in the ITR. If occasionally there is traffic for one of the other exception subprefixes, then the ITR will request a map for it at that time. Thus this method (with $MS = 11$) has the ability to significantly conserve resources at the ITR. This in itself shows a significant utility for Case 4 ($MS = 11$). Just to take this one step further, a few subsequent map requests by the ITR may gradually fetch the remaining exception maps (i.e., all $n_e = 12$ of them). At this point, the ITR has all 12 exception maps in its table. Given that the exception map picture is now complete, the ITR can now proceed and discard the redundant maps $(a_2/24, \text{ETR1})$ and $(a_5/24, \text{ETR1})$, which are covered by the less specific parent map $(a/16, \text{ETR1})$. Note that these two maps were not redundant before all exception maps were known at the ITR.

The exception subnets and their mappings may change after an ITR has received and installed the primary map and exception maps. For occasional mapping changes (of the aggregate prefix or exception subnets), it is envisaged that the ILM or ILM-R can proactively send update messages to ITRs which recently received concerning map responses. The mapping distribution protocol is not intended to be responsive to very dynamic mobility. However, for the case of mobile devices, it is helpful at least to a limited extent that the maps for the related subnets show ETR as “Re-request”. With this the ETR information for a mobile device is generally requested just-in-time prior to connection establishment.

IV. MAPPING DISTRIBUTION FOR SCENARIOS WITH HIERARCHY OF ETRs AND MULTI-HOMING

Now we refer to Fig. 6 to highlight another architectural concept related to mapping management. Here we consider the possibility that ETRs may be organized in a hierarchical manner. For instance ETR7 in Fig. 6 is higher in the loose hierarchy relative to ETR1, ETR2, and ETR3, and like-wise ETR8 is higher relative to ETR4, ETR5, and ETR6. For instance, ETRs 1 through 3 can relegate locator role to ETR7 for their EID address space. In essence, they can allow ETR7 to act as the locator for the delivery networks in their purview. ETR7 keeps a local mapping table for mapping the appropriate EID address space to specific ETRs that are hierarchically associated with it in the level below. In this situation, ETR7 can perform EID address space aggregation across ETRs 1

through 3 and can also include its own immediate EID address space for the purpose of that aggregation. Thus in the example of Fig. 6, ETR7 can aggregate $x_0/24, x_1/24, x_2/24, x_3/24$ into a map message of the form $Map:(x/22, \text{ETR7})$ to inform ILM-R. Similarly, ETR8 can aggregate $y_0/24, y_1/24, y_2/24, y_3/24$ into a map message of the form $Map:(y/22, \text{ETR8})$. This architectural principle again lessens the possibility of cluttering the mapping distribution system with excessive map messages or entries. It may be noted that ETR7 and ETR8 may or may not hide the ETRs below in the hierarchy. This is because there may be prefixes (subnets) such as $z_1/24$ at ETR2 and $z_2/24$ at ETR4, which benefit by simply announcing $Map:(z_1/24, \text{ETR2})$ and $Map:(z_2/24, \text{ETR4})$, respectively. The idea is that when an ETR at the higher level is not able to aggregate EID prefixes of some ETRs below in the hierarchy, the routing locator may as well be the actual ETR where the delivery network resides.

Another architectural consideration for mapping distribution and management arises when some delivery networks (i.e., EID address space prefixes) are multi-homed to different ETRs. Examples of this in Fig. 6 are $x_3/24$ and $y_0/24$ which are each multi-homed to ETR7 and ETR8. In such case, ETR7 distributes a map message for $y_0/24$ which is a more specific of $y/22$ for which ETR8 distributes a map message. The map message for such subprefix multi-homing situations may incorporate a field as shown in Fig. 6 to indicate that the ETR in the map provides a backup or lower priority path. But it is up to the ITRs as to how they make use of the backup/priority information in such cases. They may go by the priority information in the map response or they may prefer more specifics in any case. Recommendations for those actions or choices can be made in the future based on performance and operational considerations. In summary, the takeaway from Fig. 6 is that additional EID address space aggregation opportunities exist if there is at least a loose hierarchical structure to the ETRs. However, some minor complexities can also arise in some multi-homing cases, which can be handled by suitable best common practice (BCP) recommendations. These recommendations can be established in the future based on network operators’ goals and preferences.

The illustration in Fig. 6 also brings to mind a question about whether it would be a good design choice to recursively perform map-and-encap routing via a hierarchy of ETRs. This question has been brought up for discussion in some other proposals also that have been shared in the RRG. The hierarchical organization of ETRs and delivery networks potentially also helps in the future growth and scalability of a mapping distribution protocol, albeit with some impact on mapping response delays. With recursive map-and-encap, some of the mapping distribution and management functionality will remain local to topologically neighboring delivery networks which are hierarchically underneath ETRs that reside in transit networks and serve as gateways.

V. CONCLUSION

We have discussed various architectural questions, and offered various solutions related to the mapping distribution

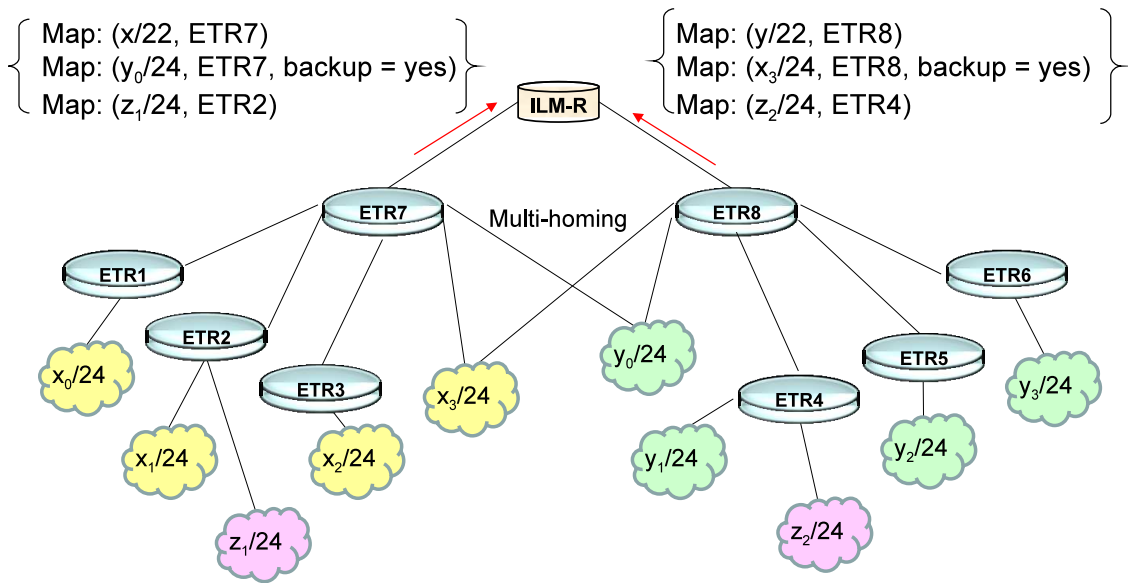


Fig. 6. Illustration of endpoint ID aggregation in the presence of multihoming.

and management in map-and-encap class of solutions for Internet routing and addressing scalability. We have proposed a methodology for aggregation possibilities for the EID address space associated with delivery networks that are largely homed at the same ETR. We introduced special considerations such as exceptions in the sense that some subprefixes may be located away at different ETRs other than the ETR that is home to bulk of a covering less specific prefix. We also discussed the notion of a loose hierarchy of ETRs with the potential benefit of aggregation of their EID address spaces. The purpose of this paper is to help generate some discussion of these issues. The overarching goal is to expose and discuss some subtleties in design considerations for mapping distribution and management. Hope is that early awareness of these issues may result in anticipating and averting some architectural roadblocks in the future Internet.

Future work in this area should address detailed quantitative evaluation of the proposed algorithms. There is also need for modeling and simulations to quantify the tradeoffs associated with various architectural concepts pertaining to scalable addressing & routing and mapping distribution protocols.

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