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NEMO Route Optimization Problem Statement and Analysis
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Status of this Memo

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Abstract

This document describes the routing optimization problem in NEMO and analyzes the related approaches to solve this problem.

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1. Introduction

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 [7].

NEMO Basic Support protocol maintains the connectivity when MR changes its point of attachment to the Internet by establishing a bi-directional tunnel between MR and HA. Like MIP6, the protocol specification introduces one level of indirection in the routing system in favor of protocol simplicity and minimal changes on fixed nodes. However, it results in a non-optimal (We will define "optimal" and "non-optimal" later.) route between MNN and CN with a non-zero and even very large probability, which causes the significant communication delay. Moreover, by using IPv6 header encapsulation together with other options, NEMO Basic Support protocol also causes big overheads in packet payload and bandwidth. NEMO RO problem introduces more challenges and more difficulties than MIP6 RO problem because of the nested NEMO network where multiple levels of mobility are formed. Without NEMO RO solution, the performance becomes much worse especially in the nested NEMO.

In this draft, we describe the routing optimization problem in NEMO and analyze the related approaches to solve this problem. In the appendixes, we also define the requirements that must be met by NEMO route optimization solutions and describe the metrics to evaluate the performance of NEMO route optimization solutions as well as the formalization of the nested NEMO network.

2. Terminology

The terms used in this draft are defined in [2], besides the following ones:

Correspondent Agent (CA): An entity (router or host) performs the RO function with MR on behalf of CN. In NEMO when MR acts as a gateway and performs RO function for an entire mobile network associated with itself, its peer is CA rather than CN that is instead the peer of MNN from an end-to-end perspective. CA may be just CN itself or a router near CN or even CN's default router. One MR could have multiple CAs at the same time because MNNs behind this MR may communicate with CNs in the different networks. And in NEMO Basic Support protocol, HA acts as CA for any node in the Internet to communicate with MNN behind its MR.

Anchor point: the entity that knows the binding information between host and location and thus is capable of forwarding the data packets destined for a host to the location directly. In the fixed network, each router is such kind of anchor point because IP address represents both location and host, and the destination IP address together with the routing table provides the sufficient knowledge on how to reach the destination. However in the NEMO mobile network that is compliant with NEMO Basic Support protocol, HA is the only anchor point for CN and MNN. In order to achieve the optimal route in NEMO, MR and CA should become anchor point too. In most cases, the closer to MNN/CN the anchor point is, the shorter the routing path is.

Inbound direction: The direction from the Internet infrastructure to the inside of NEMO network.

Outbound direction: The direction from the inside of NEMO network to the Internet infrastructure.

Inbound route : The route taken by the packets forwarded in the inbound direction. Inbound route is used exchangeably with inbound path.

Outbound route : The route taken by the packets forwarded in the outbound direction. Outbound route is used exchangeably with outbound path.

3. Assumptions

In this draft we do not consider the case of mobile HA. Instead we assume that all HAs are fixed nodes and are located in the Internet infrastructure. Firstly it is not clear yet about the need of mobile HA in the real life at this moment. Secondly and more importantly, since a mobile HA needs the help of another fixed HA in order to forward the traffic for MRs, the mobile HA case can be deduced into the similar case with only fixed HA. Our description has no difficulty to be extended into the mobile HA case. Thus we believe that this assumption is reasonable and does not prevent the thorough analysis on NEMO RO problem.

4. The definition of "optimal" and "non-optimal" route

NEMO route optimization solution aims to provide the optimal route between MNN and CN as well as between MR and CA. As it has been understood for a long time that the routing path in the Internet is asymmetric, in the following text we consider just either of two directions without explicit statement and the same analyses also apply to the other direction.

4.1 Optimal route

In the NEMO Route Optimization problem, "optimal route" is not the topologically shortest path or the best route in terms of any other metric from source to destination. Based on the location of CN, "optimal route" is discussed in the following cases:

4.1.1 CN is not under the same nested NEMO as its peer, MNN

CN may be located in either fixed or mobile network. As the route between MNN/MR and CN/CA consists of two portions, the route in the Internet and the route inside the (nested) NEMO network, we define them separately. The "optimal route" in the Internet is the route between the location of MNN/MR and the location of CN/CA based on the forwarding tables of Internet routers, which is usually built by inter-domain or intra-domain routing protocol. Precisely, location is the point of attachment to the Internet. While in MIP6 MN's Care-of-Address represents its location of attachment to the Internet, in the nested NEMO MNN/MR's Care-of-Address is not sufficient any more to represent its location of attachment to the Internet except the case of root-MR; Instead it represents the point of attachment to the parent MR or the location inside the parent NEMO. A sequence of Care-of-Addresses of MRs or other ways may be used to represent the location of MR in the NEMO RO solution.

The "optimal route" inside the NEMO network is formed by the decision of each MR along the outbound and inbound path. In the outbound direction, MR just forwards the packets to its default router that is determined when MR associates to NEMO network while in the inbound direction, MR forwards the packets to the next hop depending on the solution. The inbound path inside the NEMO network may be different from the outbound path. Note that the route inside the NEMO network does not contain HA.

4.1.2 CN is under the same nested NEMO as its peer, MNN

CN may be under the same MR or different MR from its peer. We assume that node1 wants to communicate with node2 under the same nested NEMO. Path p1 = <MR_(1,1), MR_(1,2), ..., MR_(1,m)> is the sequence

of routers inside the nested NEMO for node1 to reach node2 and path p2 = <MR_(2,1), MR_(2,2), ..., MR_(2,n)> is the sequence of routers inside the nested NEMO for node2 to reach node1.

Case 1: If the intersection of p1 and p2 is not empty, denoted by <MR_(1,i1), MR_(1,i2), ..., MR_(1,ik)> = <MR_(2,j1), MR_(2,j2), ..., MR_(2,jk)> where i1 < i2 < ... < ik and j1 < j2 < ... < jk, then ideally the optimal path between node1 and node2 is <MR_(1,1), MR_(1,2), ..., MR_(1,i1), MR_(2,j1-1), ..., MR_2,2, MR_2,1>. Note that MR_(1,i1) is equal to MR_(2,j1).

```
                            |-----|   |-----|
                        |---| MR2 |---| MR3 |--LFN3
                        |   |-----|   |-----|
      |-------|   |-----|
      |Root-MR|---| MR1 |
      |-------|   |-----|
                        |   |-----|   |-----|
                        |---| MR4 |---| MR5 |--LFN5
                            |-----|   |-----|
```

Figure 1: The optimal route inside the nested NEMO

For example, in the nested NEMO shown by Figure 1, the optimal route between LFN3 and LFN5 is MR3<->MR2<->MR1<->MR4<->MR5.

The optimal route in this case is the route turning around at the first MR that is aware of how to forward the data packets from source to destination without going out of the nested NEMO. However, in NEMO Basic Support protocol, the data packet takes a route that goes out of the nested NEMO and comes back to the same nested NEMO again.

Case 2: If the intersection of p1 and p2 is empty (It may be due to multiple different root-MRs and no inter-communication between them), the "optimal route" inside the nested NEMO consists of both p1 and p2, and the "optimal route" inside the Internet follows the definition in Section 4.1.1.

4.2 Non-optimal route

In NEMO Basic Support protocol, the packets are forwarded to an intermediate box, HA, in both directions rather than the location of destination directly, which results in a longer route than the "optimal route" with a high probability. We refer this kind of route as "non-optimal" route. Worse than MIP6, in the nested NEMO network the packets are forwarded to multiple HAs in both directions before arriving at the location of destination. [14] describes the

non-optimal route that packets would take using existing Mobile IPv6 and NEMO Basic Support mechanisms

4.3 Approximately optimal route

The solution to achieve an "optimal route" has to consider a lot of other factors, for example, scalability, efficiency, and security, to name a few. Although the solution may result in an approximately optimal route, it must be the best overall when all the related issues are taken into consideration.

5. Limitation of NEMO Basic Support protocol

In this section, we analyze the limitation of NEMO Basic Support protocol and the reasons to cause the non-optimal route.

5.1 Reverse tunneling

In NEMO Basic Support protocol, all the packets forwarded by MR in the outbound direction have to go through HA firstly. If the reverse tunnel would be removed in NEMO RO solution, it is equivalent to the case where MR is the anchor point for the outbound packet.

Instead in the normal fixed network, the data packets are sent to the destination directly.

5.2 HA as the only anchor point

Since MR is refrained from announcing its MNP to the infrastructure due to the conflicts and routing instability issues, HA is the only anchor point for MNN as well as CN and thus the packets destined to MNNs can be served only by HA. Even worse in the nested NEMO, the packets inevitably have to go through multiple HAs in order to be forwarded to MNN correctly.

The non-optimal route is formed because the binding information is available in HA only and the HA's location is limited in home network only. Image that there are as many HAs as routers scattering around the Internet, every data packet from CN is forwarded by a nearby HA and takes at least a nearly optimal route. Deploying multiple HAs in the different domains or spreading binding information needs to consider a lot of issues, such as fundamental changes, conflict and scalability etc.

Compared with the fixed network, there is no limitation on the location of anchor point because each router is such an anchor point.

5.3 Inside the nested NEMO

If MR inside the nested NEMO is refrained from announcing its MNP to other MRs, MR does not know how to forward in the inbound direction just based on the destination IP address and its own limited knowledge of topology. Thus MR has to depend on the explicit IP-in-IP header to forward to the next hop, which in return requires that each data packet should go through HA.

5.4 Data plane based method

We categorize NEMO as a data plane method because 1) there is no

signaling message introduced for CN to discover or update the binding information; 2) many changes are made in order for the routing decision to be explicitly carried in the data packet in an "in-band" fashion. The limitation of this data plane method is that every data packet has to experience the non-optimal route even though the optimal route may be existing and fairly stable within a certain time window. Considering the potential large number of data packets, the inefficiency as well as the benefits if the problem is solved are very big.

On the other hand this method avoids the large change on the infrastructure.   Given the fact that a big change on the infrastructure may take a longer time to deploy, a RO solution in data plane may qualify as a necessary step before a revolutionary change happens.

5.5 Data packet and processing overhead

Encapsulation and other options in IPv6 header cause the overhead in data packet and bandwidth, packet fragmentation, and the processing overhead in MR and HA especially in the nested NEMO where every level of mobility introduces one encapsulation together with applicable option fields into the data packet.

In the fixed network, encapsulation and other options are not needed since all the routing decision is purely based on the forwarding table and the destination IP address.

5.6 Summary

One significant difference between MIP6 and NEMO is the management granularity that is a single host in MIPv6 and a mobile network in NEMO. Another significant difference is the multiple levels of mobility in the nested NEMO, which not only causes much longer routing path and bigger overhead in the data payload but also more challenges when attempting to solve NEMO RO problem, for example, given that any other factor is constant, the number of messages (RR test, BU etc) is in direct proportion to the number of MRs along the path if no cooperation among them. In summary, NEMO RO problem is a challenging problem and requires a well-designed NEMO RO solution.

6. The related tradeoff

We discuss the tradeoffs when designing the solution for NEMO RO problem.

6.1 Data plane method vs. signaling plane method

Data plane method needs fewer changes but introduces more overheads while signaling plane method may require more changes on the protocols. We need to consider how to utilize the advantages of both methods and avoid the disadvantages.

6.2 Optimization vs. the scalability issue in MR, CA and HA

The closer to CN CA is, the more optimal route; but MR has to perform RO functions with more CAs when the number of different CNs is large and all CNs scatter around the Internet. MR may choose not to perform RO function but NEMO Basic Support protocol due to the management cost.

On the other hand, if there are many MRs belonging to the same home network scattering around the Internet, because of the same reason, CA may also choose to perform NEMO Basic Support protocol with HA rather than to perform RO function with each MR.

If there are many HAs, each of which is close to each MR belonging to the same home network, the route between MNN and CN is at least nearly optimal. Thus there is a tradeoff between the optimal route and the scalability issue in terms of the number of HAs.

6.3 Optimization vs. the scope of change

The scope of change is in terms of the number of nodes that need to be changed in order to support NEMO RO solution. If all CNs are changed to support the NEMO RO, the optimal route is formed; however, if the scope of change is a limited number of nodes, the probability that a sub-optimal route is formed could be very large.

6.4 Location privacy vs. optimal route

Bi-direction tunnel in NEMO Basic Support protocol can maintain some level of location privacy. A potential RO solution may require some location information to be revealed in order to facility route optimization.

6.5 Security vs. optimal route

In NEMO Basic Support protocol, it is very possible that there pre-

exists the security association between MR and HA, which helps resist the various attacks. However in NMEO RO solution, as the MR-HA tunnel may not exist and there is no pre-existing security association between two entities from the different domains, it is more challenging to maintain the same security strength as in NEMO Basic Support protocol.

6.6 Scalability vs. reliability

This is a general tradeoff in NEMO. As MR manages a whole mobile network, when MR fails due to attack or error, a bunch of MNNs behind MR lose the connectivity even though any single MNN still functions well. However, generally it provides more scalability than MIP6.

7. The scope of NEMO RO problem

7.1 What NEMO RO considers

(Below is an incomplete list of issues related to NEMO RO problem quoted from the NEMO mailing list. More discussions are still needed.)

- o NEMO The optimal route when two communicating nodes are located either in the same or different (nested) NEMO network [14].

- o VMN may choose not to perform MIP6 RO solution so that even though MR performs NEMO RO function, the packets originated from and destined to VMN still have to go through VMN's HA. We need to consider all the related issues if we want to remove this kind of sub-optimal route for VMN.

- o Missing signaling messages when performing NEMO RO

- o Obsolete state or signaling message when mobility causes the topology changes

- o RO problem when multi-homing is also involved

- o Data packet overhead when header encapsulation, options and routing header are used

- o Security problem.

- o Location privacy problem

- o Looping problem

- o Cross-over tunnel problem

- o BU storm

7.2 What NEMO RO does not consider

TBD.

8. The analysis of related approaches

In this section, we analyze the related approaches. Generally a NEMO RO solution should make the anchor point close to either CN or MNN. One exmaple of the latter is HA-HA protocol [10][11][12]. However since the latter may only achieve the approximate optimal route in some situations, we focus on a large range of approaches that aim at making the binding information available to CN/CR directly in the following discussion.

From NEMO RO problem described and analyzed before, we expect a NEMO RO solution to answer the following questions:

- Q1: How to represent/achieve the full binding information between Home_Address/Home_Network_Prefix and the point of attachment to a specific router (AR when CN is not under the same nested NEMO network or the first common MR when CN is under the same nested NEMO network ideally.).

- Q2: How to transfer this information from HA/MR to CN/CR/other routers (other MR/AR that is close to CN).

- Q3: How to route the data packet based on the available full binding information.

The related approaches are categorized to answer Q1, Q2, and Q3 respectively and the related issues are analyzed in the following.

8.1 Question 1

Since the information of Home_address/Home_network_prefix is already available to MR and HA, we focus on the information about the point of attachment:

8.1.1 The point of attachment to AR

- A sequence of CoAs

  The information about each upstream MR's CoA is collected thus a sequence of CoAs is formed to represent the point of attachment to AR. There are several different methods to do that. For example, in RRH [9] each upstream MR's CoA is attached to one payload in the data packet; it is also possible for MR/MNN to send the specific formatted packet to collect the information of upstream MRs.

  Issues: This approach requires a dedicated payload in each data packet to store the sequence of CoAs. Thus the overhead in the

data packet may become very large when there are multiple nested MRs in the NEMO network.

The issues related to the probing method are that a probing procedure is needed and the collected information may become invalid if some MR moves after the probing.

How to determine the length of the payload is the issue related to the other method. If we allow this payload to contain arbitrary number of CoAs, the data packet might be fragmented during the transmission. On the other hand, if the information of the nested levels in the NEMO network is not available when MR starts the communication, the fixed length payload could result in either the partial optimized route (The payload cannot contain all the CoAs.) or the wasted payload/bandwidth (Part of payload is not used.).

Security issue has to be considered if there is an eavesdropper or malicious MR on the path.

- Prefix delegation

  This approach removes the need of a sequence of CoAs by using prefix delegation from the one owned by AR to enable each MR inside the nested NEMO network to achieve a globally routable CoA as a primary CoA and establish the routing table accordingly.

  Issues: The related protocol and message need to be extended. One nice thing is that the prefixes delegated to each MR can be aggregated.

- Routing protocol

  This approach allows MR to establish routing table or other kind of soft states about how to forward the data packets.

  Issues: Updating routing table or soft state may require some signaling message or specific payload in the data packet. And the authenticity of such information needs to be guaranteed. Once the states are established correctly, the data packet could be transmitted in a normal IPv6 format.

- CN deduces from a sequence of BU packets or BC entries.

  Each MR sends the BU message to CN and CN looks up its BC (maybe for multiple times) to retrieve the full binding information.

Issues: Besides the time used to look up the BC, there may be some redundancy if each MR needs to send the BU message to CN individually.

8.1.2 The point of attachment to MR

Similar with those described above.

8.1.3 Some common issues

Authorization issue: Each mechanism needs the authorization of upstream MR to collect the information along the path in order to achieve the complete optimal route.

Authentication issue: The authentication of information needs to be protected against eavesdropper and malicious MR on the path. However the strength of protection might vary under the different assumptions.

8.2 Question 2

To answer this question, firstly we have to consider which one initializes the NEMO RO signaling procedure, MR/HA or CN/CR.

- CN/CR as an initiator

  If MNN is a mobile server, CN/CR might have the motivation to initialize the route optimization procedure in order to improve the communication performance. This case might be rare in practice, but if it wants to, CN/CR needs a mechanism to detect whether MR is away from the home network.

- MR/HA as an initiator

  Usually MR initializes the procedure and the information flow is from MR.

The security issues: MR/HA must register MNP and HoA with CN or CR in a secure way when there is no pre-existing security association between MR/HA and CN/CR. Similar with that in MIP6 RO mechanism, a RR test on network prefix may be used to enhance the security [15][16].

8.3 Question 3

- IP-in-IP

- Routing header and other options

It is required that MR can process the new types of routing header or options. Please note that the processing on routers in the Internet should be avoided.

- o Combination of these two.

9. Acknowledgement

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Appendix A. Requirements

The goal of NEMO RO solution is to provide an optimal route between any two nodes regradless of the location, the configuration, and the type etc. Besides those defined in [1], NEMO RO solution, hereafter referred to as "the solution", must meet the following requirements that are described in the descending order of importance as follows:

R1: When any MR in NEMO performs NEMO RO function, the route taken by the traffic from this MR together with any MNN inside this MR's sub-NEMO MUST be better than the one resulted in by performing NEMO Basic Support protocol.

R2: Signaling messages MUST be secured to guarantee the integrity, confidentiality, anti-replay and authorization. The insider attack where the attacker is on the routing path SHOULD be at least detected while the outsider attack where the attacker is not on the routing path MUST be resisted. The security mechanism MUST prevent the forged packet being forwarded in a loop inside NEMO and MUST not generate the new vulnerability. Overall, the security level and the location privacy MUST be kept as strong as in NEMO Basic Support protocol.

R3: This solution SHOULD introduce limited signaling overhead, limited packet payload overhead, limited memory cost needed for processing, limited complexity in term of data structure and protocol state machine transition.

R4: The solution MUST be able to support a potentially large number of MNNs, CNs, CAs as well as HAs (if applicable) and arbitrary levels of MRs unless because of other constraints.

R5: The solution SHOULD avoid too many changes on MNN/MR/CN/CA/HA unless the significant performance improvement can be achieved. It is desired to keep the mobility transparency for MNN behind MR.

R6: The solution SHOULD be able to handle the topology changes in any kind of mobility pattern very well and minimize the impact of handover over applications, in term of packet loss or delay.

R7: The solution SHOULD function for multi-homing NEMO networks (multiple MNPs, multiple MRs and multiple network interfaces, etc.). The solution SHOULD not conflict with multi-homing mechanism, such as loading balance, fault tolerance etc.

R8: Each MR can either independently decide whether to perform RO function or NEMO Basic Support protocol or collaborate with other MR based on its policy. The decision made by one MR MUST not

prevent other MR performing either NEMO RO or NEMO Basic Support protocol properly.

R9: The solution SHOULD ensure backward compatibility with other standards defined by the IETF. Especially the solution MUST not prevent the proper operation of Mobile IPv6 (i.e. the solution MUST allow MIP6-enabled MNNs to operate either of the CN, HA, or MN operations defined in MIP6.) and NEMO Basic Support protocol.

More?

Appendix B. Evaluation Considerations

The following metrics are defined to evaluate how good a NEMO RO solution is besides meeting the requirements described above. Each metric may be assigned a weight in order to find a overall best RO solution.

- Level of compatibility with NEMO Basic Support protocol

- Complexity: How many changes to MNN/MR/CA/HA are introduced? Does the solution maintain the mobility transparency for MNN?

- Performence:
  * The delay to discover and set up the optimal path
  * The packet overhead and/or signaling overhead to discover and set up the optimal path
  * The delay to re-discover and re-build the optimal path when the mobility causes the topology change
  * The packet overhead and/or signaling overhead to re-discover and re-build the optimal path when the mobility causes the topology change

- Management cost:
  * The number of states established or maintained in MR/CA/HA
  * The number of MNNs supported by MR/CA/HA

- More?

Appendix C. The formalization of the nested NEMO network

The topology of the nested NEMO can be formalized into graph. When care is taken to avoid the loop to be formed, this graph is a Directed Acyclic Graph that may be also considered as a set of multiple overlapping trees.

The inbound graph is a direct graph <V, E> where each node in V denotes a MR and if one of egress interfaces in MRj gets its care-of-address from one MNP owned by MRi, the link from MRi to MRj, <MRi, MRj> belongs to the edge set E.

The outbound graph is a direct graph <V, E> where each node in V denotes a MR and if MRj chooses MRi as its default router, the link from MRj to MRi, <MRj, MRi> belongs to the edge set E.

This method can also formalize a multi-homing nested NEMO where there could be more than one egress interface associated with one MR and more than one MR owning one or more MNPs. Figure 2 below shows an exmaple of nested NEMO network where MR1 announces MNP1 and MNP2 while MR2 announces MNP2; MR3 has two interfaces that associate with MR1 and MR2 respectively while MR4 associates with MR2 only.

```
                  |-------|                 |-------|
                  |  MR1  |                 |  MR2  |
                  |-------|                 |-------|
                    |  |                        |
               MNP1 |  | MNP2              MNP2 |
           --?------+  +-------?------?----------+
             |                 |      |
             |                 |      |
             |eth0|-------|eth1|      |eth0|-------|
             |----|  MR3  |----|      |----|  MR4  |
                  |-------|                |-------|
```

Figure 2: An example of nested NEMO network

The inbound graph is shown in Figure 3.

```
                        |-------|           |-------|
                        |  MR1  |---     ---|  MR2  |
                        |-------|   \   /   |-------|
                          |  |       \ /        |
                          V  V        X         V
                        |-------|    / \    |-------|
                        |  MR3  |<--/   \-->|  MR4  |
                        |-------|           |-------|
```

Figure 3: The inbound graph of a nested NEMO network

We can simplify the inbound graph shown in Figure 3 into the following one.

```
                        |-------|           |-------|
                        |  MR1  |---     ---|  MR2  |
                        |-------|   \   /   |-------|
                            |        \ /        |
                            V         X         V
                        |-------|    / \    |-------|
                        |  MR3  |<--/   \-->|  MR4  |
                        |-------|           |-------|
```

Figure 4: The simplified inbound graph of a nested NEMO network

Assume that MR3 chooses MR2 as the default router through eth1 and MR4 chooses MR1 as the default router through eth0. The outbound graph of this nested NEMO is shown in Figure 5.

```
                        |-------|           |-------|
                        |  MR1  |<--     -->|  MR2  |
                        |-------|   \   /   |-------|
                                     \ /
                                      X
                        |-------|    / \    |-------|
                        |  MR3  |---/   \---|  MR4  |
                        |-------|           |-------|
```

Figure 5: The outbound graph of a nested NEMO network

The formalization may help us understand the problem better and develop the RO solution. For example, if an explicit next hop address is presented in the packet, MR has to check whether this next hop address belongs to one of its MNPs in order to prevent an attacker forcing the packet to be forwarded in a loop.

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