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**Virtual Machine Mobility Solutions for L2 and L3 Overlay Networks**  
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**Abstract**

This document describes virtual machine (VM) mobility solutions commonly used in data centers built with an overlay network. This document is intended for describing the solutions and the impact of moving VMs, or applications, from one rack to another connected by the overlay network.

For layer 2, it is based on using an NVA (Network Virtualization Authority) to NVE (Network Virtualization Edge) protocol to update ARP (Address Resolution Protocol) tables or neighbor cache entries after a VM moves from an old NVE to a new NVE. For Layer 3, it is based on address and connection migration after the move.

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## Table of Contents

<a href="#">1. Introduction.....</a>	<a href="#">3</a>
<a href="#">2. Conventions used in this document.....</a>	<a href="#">4</a>
<a href="#">3. Requirements.....</a>	<a href="#">5</a>
<a href="#">4. Overview of the VM Mobility Solutions.....</a>	<a href="#">6</a>
<a href="#">4.1. Inter-VN and External Communication.....</a>	<a href="#">6</a>
<a href="#">4.2. VM Migration in a Layer 2 Network.....</a>	<a href="#">6</a>
<a href="#">4.3. VM Migration in Layer-3 Network.....</a>	<a href="#">8</a>
<a href="#">4.4. Address and Connection Management in VM Migration.....</a>	<a href="#">9</a>

<a href="#">5. Handling Packets in Flight.....</a>	<a href="#">10</a>
<a href="#">6. Moving Local State of VM.....</a>	<a href="#">10</a>
<a href="#">7. Handling of Hot, Warm and Cold VM Mobility.....</a>	<a href="#">11</a>
<a href="#">8. Other Options.....</a>	<a href="#">12</a>
<a href="#">9. VM Lifecycle Management.....</a>	<a href="#">13</a>
<a href="#">10. Security Considerations.....</a>	<a href="#">13</a>
<a href="#">11. IANA Considerations.....</a>	<a href="#">14</a>
<a href="#">12. Acknowledgments.....</a>	<a href="#">14</a>
<a href="#">13. Change Log.....</a>	<a href="#">14</a>
<a href="#">14. References.....</a>	<a href="#">14</a>
<a href="#">14.1. Normative References.....</a>	<a href="#">14</a>
<a href="#">14.2. Informative References.....</a>	<a href="#">16</a>

## [1. Introduction](#)

**This document describes the overlay-based data center network solutions in support of multitenancy and VM mobility.** Being able to move VMs dynamically, from one server to another, makes it possible for dynamic load balancing or work distribution. Therefore, dynamic VM Mobility is highly desirable for large scale multi-tenant DCs.

This document is strictly within the DCVPN, as defined by the NV03 Framework [[RFC 7365](#)]. The intent is to describe Layer 2 and Layer 3 Network behavior when VMs are moved from one NVE to another. This document assumes that the VM's move is initiated by the VM management system, i.e. planed move. How and when to move VMs is out of the scope of this document. [RFC7666](#) already has the description of the MIB for VMs controlled by Hypervisor. The impact of VM mobility on higher layer protocols and applications is outside its scope.

Many large DCs (Data Centers), especially Cloud DCs, host tasks (or workloads) for multiple tenants. A tenant can be an organization or a department of an organization. There are communications among tasks belonging to one tenant and communications among tasks belonging to different tenants or with external entities.

Server Virtualization, which is being used in almost all of today's data centers, enables many VMs to run on a single physical computer or server sharing the processor/memory/storage. Network connectivity among VMs is provided by the network virtualization edge (NVE) [[RFC8014](#)]. It is highly desirable [[RFC7364](#)] to allow VMs to be moved dynamically (live, hot, or cold move) from one server to another for dynamic load balancing or optimized work distribution.

There are many challenges and requirements related to VM mobility in large data centers, including dynamic attachment and detachment of VMs to/from Virtual Network Edges (VNEs). In addition, retaining IP addresses after a move is a key requirement [RFC7364]. Such a requirement is needed in order to maintain existing transport layer connections.

In traditional Layer-3 based networks, retaining IP addresses after a move is generally not recommended because frequent moves will cause fragmented IP addresses, which introduces complexity in IP address management.

In view of the many VM mobility schemes that exist today, there is a desire to document comprehensive VM mobility solutions that cover both IPv4 and IPv6. The large Data Center networks can be organized as one large Layer-2 network geographically distributed in several buildings/cities or Layer-3 networks with large number of host routes that cannot be aggregated as the result of frequent moves from one location to another without changing their IP addresses. The connectivity between Layer 2 boundaries can be achieved by the NVE functioning as a Layer 3 gateway router across bridging domains.

## **2. Conventions used in this document**

This document uses the terminology defined in [RFC7364]. In addition, we make the following definitions:

VM: Virtual Machine

Task: A task is a program instantiated or running on a VM or a container. Tasks running in VMs or containers can be migrated from one server to another. We use task, workload and VM interchangeably in this document.

Hot VM Mobility: A given VM could be moved from one server to another in a running state without terminating the VM.

Warm VM Mobility: In case of warm VM mobility, the VM states are mirrored to the secondary server (or domain) at predefined regular intervals. This reduces the

overheads and complexity, but this may also lead to a situation when both servers may not contain the exact same data (state information)

**Cold VM Mobility:** A given VM could be moved from one server to another in stopped or suspended state.

**Old NVE:** refers to the old NVE where packets were forwarded to before migration.

**New NVE:** refers to the new NVE after migration.

**Packets in flight:** refers to the packets received by the old NVE sent by the correspondents that have old ARP or neighbor cache entry before VM or task migration.

**Users of VMs in diskless systems or systems not using configuration files** are called end user clients.

**Cloud DC:** Third party data centers that host applications, tasks or workloads owned by different organizations or tenants.

### 3. Requirements

This section states requirements on data center network VM mobility.

- Data center network should support both IPv4 and IPv6 VM mobility.
- VM mobility should not require changing an VM's IP address(es) after the move.
- "Hot Migration" requires the transport service continuity across the move, while in "Cold Migration" the transport service is restarted, i.e. the task is stopped on the old NVE, is moved to the new NVE and then restarted. Not all DCs support "Hot Migration. DCs that only support Cold Migration should make their customers aware of the potential service interruption during a Cold Migration.
- VM mobility solutions/procedures should minimize triangular routing except for handling packets in flight.
- VM mobility solutions/procedures should not need to use tunneling except for handling packets in flight.

## **4. Overview of the VM Mobility Solutions**

### **4.1. Inter-VN and External Communication**

Inter VN (Virtual Network) communication refers to communication among tenants (or hosts) belonging to different VNs. Those tenants can be attached to the NVEs co-located in the same Data Center or in different Data centers. When a VM communicates with an external entity, the VM is effectively communicating with a peer in a different network or a globally reachable host.

This document assumes that the inter-VNs communication and the communication with external entities are via NV03 Gateway functionality as described in [Section 5.3 of RFC 8014](#) [RFC8014]. NV03 Gateways relay traffic onto and off of a virtual network, enabling communication both across different VNs and with external entities.

NV03 Gateway functionality enforces appropriate policies to control communication among VNs and with external entities (e.g., hosts).

Moving a VM to a new NVE may move the VM away from the NV03 Gateway(s) used by the VM's traffic, e.g., some traffic may be better handled by an NV03 Gateway that is closer to the new NVE than the NV03 Gateway that was used before the VM move. If NV03 Gateway changes are not possible for some reason, then the VM's traffic can continue to use the prior NV03 Gateway(s), which may have some drawbacks, e.g., longer network paths.

### **4.2. VM Migration in a Layer 2 Network**

In a Layer-2 based approach, a VM moving to another NVE does not change its IP address. But this VM is now under a new NVE, previously communicating NVEs may continue sending their packets to the old NVE. Therefore, the previously communicating NVEs need to promptly update their Address Resolution Protocol (ARP) caches of IPv4 [RFC0826] or neighbor caches of IPv6 [RFC4861]. If the VM being moved has communication with external entities, the NV03 gateway needs to be notified of the new NVE where the VM is moved to.

In IPv4, the VM immediately after the move should send a gratuitous ARP request message containing its IPv4 and Layer 2 MAC address in its new NVE. Upon receiving this message, the new NVE



can update its ARP cache. The new NVE should send a notification of the newly attached VM to the central directory [[RFC7067](#)] embedded in the NVA to update the mapping of the IPv4 address & MAC address of the moving VM along with the new NVE address. An NVE-to-NVA protocol is used for this purpose [[RFC8014](#)]. The old NVE, upon a VM is moved away, should send an ARP scan to all its attached VMs to refresh its ARP Cache.

Reverse ARP (RARP) which enables the host to discover its IPv4 address when it boots from a local server [[RFC0903](#)], is not used by VMs if the VM already knows its IPv4 address (most common scenario). Next, we describe a case where RARP is used.

There are some vendor deployments (diskless systems or systems without configuration files) wherein the VM's user, i.e. end-user client asks for the same MAC address upon migration. This can be achieved by the clients sending RARP request message which carries the MAC address looking for an IP address allocation. The server, in this case the new NVE needs to communicate with NVA, just like in the gratuitous ARP case to ensure that the same IPv4 address is assigned to the VM. NVA uses the MAC address as the key in the search of ARP cache to find the IP address and informs this to the new NVE which in turn sends RARP reply message. This completes IP address assignment to the migrating VM.

Other NVEs that have attached VMs or the NV03 Gateway that have external entities communicating with this VM may still have the old ARP entry. To avoid old ARP entries being used by other NVEs, the old NVE upon discovering a VM is detached should send a notification to all other NVEs and its NV03 Gateway to time out the ARP cache for the VM [[RFC8171](#)]. When an NVE (including the old NVE) receives packet or ARP request destined towards a VM (its MAC or IP address) that is not in the NVE's ARP cache, the NVE should send query to NVA's Directory Service to get the associated NVE address for the VM. This is how the old NVE tunneling these in-flight packets to the new NVE to avoid packets loss.

When VM address is IPv6, the operation is similar:

In IPv6, after the move, the VM immediately sends an unsolicited neighbor advertisement message containing its IPv6 address and Layer-2 MAC address to its new NVE. This message is sent to the IPv6 Solicited Node Multicast Address corresponding to the target address which is the VM's IPv6 address. The NVE receiving this message should send request to update VM's neighbor cache entry in the central directory of the NVA. The NVA's neighbor cache entry should include IPv6 address of the VM, MAC address of the VM and





the NVE IPv6 address. An NVE-to-NVA protocol is used for this purpose [[RFC8014](#)].

To avoid other NVEs communicating with this VM using the old neighbor cache entry, the old NVE upon discovering a VM being moved or VM management system which initiates the VM move should send a notification to all NVEs to timeout the ND cache for the VM being moved. When a ND cache entry for those VMs times out, their corresponding NVEs should send query to the NVA for an update.

#### **4.3. VM Migration in Layer-3 Network**

Traditional Layer-3 based data center networks usually have all hosts (tasks) within one subnet attached to one NVE. By this design, the NVE becomes the default route for all hosts (tasks) within the subnet. But this design requires IP address of a host (task) to change after the move to comply with the prefixes of the IP address under the new NVE.

A VM migration in Layer 3 Network solution is to allow IP addresses staying the same after moving to different locations. The Identifier Locator Addressing or ILA [[I-D.herbert-intarea-ila](#)] is one of such solutions.

Because broadcasting is not available in Layer-3 based networks, multicast of neighbor solicitations in IPv6 and ARP for IPv4 would need to be emulated. Scalability of the multicast (such as IPv6 ND and IPv4 ARP) can become problematic because the hosts belonging to one subnet (or one VLAN) can span across many NVEs. Sending broadcast traffic to all NVEs can cause unnecessary traffic in the DCN if the hosts belonging to one subnet are only attached to a very small number of NVEs. It is preferable to have a directory [[RFC7067](#)] or NVA to manage the updates to an NVE of the potential other NVEs a specific subnet may be attached and get periodic reports from an NVE of all the subnets being attached/detached, as described by [RFC8171](#).

Hot VM Migration in Layer 3 involves coordination among many entities, such as VM management system and NVA. Cold task migration, which is a common practice in many data centers, involves the following steps:

- Stop running the task.
- Package the runtime state of the job.



- Send the runtime state of the task to the new NVE where the task is to run.
- Instantiate the task's state on the new machine.
- Start the tasks for the task continuing from the point at which it was stopped.

[RFC7666](#) has the more detailed description of the State Machine of VMs controlled by Hypervisor

#### **4.4. Address and Connection Management in VM Migration**

Since the VM attached to the new NVE needs to be assigned with the same address as VM attached to the old NVE, extra processing or configuration is needed, such as:

- Configure IPv4/v6 address on the target VM/NVE.
- Suspend use of the address on the old NVE. This includes the old NVE sending query to NVA upon receiving packets destined towards the VM being moved away. If there is no response from NVA for the new NVE for the VM, the old NVE can only drop the packets. Referring to the VM State Machine described in [RFC7666](#).
- Trigger NVA to push the new NVE-VM mapping to other NVEs which have the attached VMs communicating with the VM being moved.

Connection management for the applications running on the VM being moved involves reestablishing existing TCP connections in the new place.

The simplest course of action is to drop all TCP connections to the applications running on the VM during a migration. If the migrations are relatively rare events in a data center, impact is relatively small when TCP connections are automatically closed in the network stack during a migration event. If the applications running are known to handle this gracefully (i.e. reopen dropped connections) then this approach may be viable.

More involved approach to connection migration entails a proxy to the application (or the application itself) to pause the connection, package connection state and send to target, instantiate connection state in the peer stack, and restarting the connection. From the time the connection is paused to the time it is running again in the new stack, packets received for the connection could be silently dropped. For some period of time,

the old stack will need to keep a record of the migrated connection. If it receives a packet, it can either silently drop the packet or forward it to the new location, as described in [Section 5](#).

## **5. Handling Packets in Flight**

The old NVE may receive packets from the VM's ongoing communications. These packets should not be lost; they should be sent to the new NVE to be delivered to the VM. The steps involved in handling packets in flight are as follows:

**Preparation Step:** It takes some time, possibly a few seconds for a VM to move from its old NVE to a new NVE. During this period, a tunnel needs to be established so that the old NVE can forward packets to the new NVE. The old NVE gets the new NVE address from its NVA assuming that the NVA gets the notification when a VM is moved from one NVE to another. It is out of the scope of this document on which entity manages the VM move and how NVA gets notified of the move. The old NVE can store the new NVE address for the VM with a timer. When the timer expired, the entry for the new NVE for the VM can be deleted.

**Tunnel Establishment - IPv6:** Inflight packets are tunneled to the new NVE using the encapsulation protocol such as VXLAN in IPv6.

**Tunnel Establishment - IPv4:** Inflight packets are tunneled to the new NVE using the encapsulation protocol such as VXLAN in IPv4.

**Tunneling Packets - IPv6:** IPv6 packets received for the migrating VM are encapsulated in an IPv6 header at the old NVE. The new NVE decapsulates the packet and sends IPv6 packet to the migrating VM.

**Tunneling Packets - IPv4:** IPv4 packets received for the migrating VM are encapsulated in an IPv4 header at the old NVE. The new NVE decapsulates the packet and sends IPv4 packet to the migrating VM.

**Stop Tunneling Packets:** When the Timer for storing the new NVE address for the VM expires. The Timer should be long enough for all other NVEs that need to communicate with the VM to get their NVE-VM cache entries updated.

## **6. Moving Local State of VM**

**In addition to the VM mobility related signaling (VM Mobility Registration Request/Reply),** the VM state needs to be transferred to the new NVE. The state includes its memory and file system if

the VM cannot access the memory and the file system after moving to the new NVE.

The mechanism of transferring VM States and file system is out of the scope of this document. Referring to [RFC7666](#) for detailed information.

## **7. Handling of Hot, Warm and Cold VM Mobility**

**Both Cold and Warm VM mobility (or migration) refer to the complete shut down of the VM at the old NVE before restarting the VM at the new NVE. Therefore, all transport services to the VM need to be restarted.**

In this document, all VM mobility is initiated by VM Management System. In case of Cold VM mobility, the exchange of states between the old NVE and the new NVE occurs after the VM attached to the old NVE is completely shut down. There is a time delay before the new VM is launched. The cold mobility option can be used for non-mission-critical applications and services that can tolerate interruptions of TCP connections.

For Hot VM Mobility, a VM moving to a new NVE does not change its IP address and the service running on the VM is not interrupted. The VM needs to send a gratuitous Address Resolution message or unsolicited Neighbor Advertisement message upstream after each move.

In case of Warm VM mobility, the functional components of the new NVE receive the running status of the VM at frequent intervals., Consequently it takes less time to launch the VM under the new NVE. Other NVEs that communicate with the VM can be notified promptly about the VM migration c. The duration of the time interval determines the effectiveness (or benefit) of Warm VM mobility. The larger the time duration, the less effective the Warm VM mobility becomes.

In case of Cold VM mobility, the VM on the old NVE is completely shut down and the VM is launched on the new NVE. To minimize the chance of the previously communicating NVEs sending packets to the old NVE, the NVA should push the updated ARP/neighbor cache entry to all previously communicating NVEs when the VM is started on the new NVE. Alternatively, all NVEs can periodically pull the updated ARP/neighbor cache entry from the NVA to shorten the time span that packets are sent to the old NVE.

Upon starting at the new NVE, the VM should send an ARP or Neighbor Discovery message.

## 8. Other Options

**Hot, Warm and Cold mobility are planned activities which are managed by VM management system.**

For unexpected events, such as overloads and failure, a VM might need to move to a new NVE without any service interruption, and this is called Hot VM Failover in this document. In such case, there are redundant primary and secondary VMs whose states are continuously synchronized by using methods that are outside the scope of this draft. If the VM in the primary NVE fails, there is no need to actively move the VM to the secondary NVE because the VM in the secondary NVE can immediately pick up and continue processing the applications/services.

The Hot VM Failover is transparent to the peers that communicate with this VM. This can be achieved via distributed load balancing when both active VM and standby VM share the same TCP port and same IP address, . In the absence of a failure, the new VM can pick up providing service while the sender (peer) continues to receive Ack from the old VM. If the situation (loading condition of the primary responding VM) changes the secondary responding VM may start providing service to the sender (peers). When a failure occurs, the sender (peer) may have to retry the request, so this structure is limited to requests that can be safely retried.

If the load balancing functionality is not used, the Hot VM Failover can be made transparent to the sender (peers) without relying on request retry and by using the techniques that are described in [section 4](#). This does not depend on the primary VM or its associated NVE doing anything after the failure. This restriction is necessary because a failure that affects the primary VM may also cause its associated NVE to fail. For example, a physical server failure can cause the VM and its NVE to fail.

The Hot VM Failover option is the costliest mechanism, and hence this option is utilized only for mission-critical applications and services.

## **9. VM Lifecycle Management**

**The VM lifecycle management is a complicated task, which is beyond the scope of this document.** Not only it involves monitoring server utilization, balancing the distribution of workload, etc., but also needs to support seamless migration of VM from one server to another.

## **10. Security Considerations**

**Security threats for the data and control plane for overlay networks** are discussed in [[RFC8014](#)]. ARP (IPv4) and ND (IPv6) are not secure, especially if they can be sent gratuitously across tenant boundaries in a multi-tenant environment.

In overlay data center networks, ARP and ND messages can be used to mount address spoofing attacks from untrusted VMs and/or other untrusted sources. Examples of untrusted VMs are the VMs instantiated with the third party applications that are not written by the tenant of the VMs. Those untrusted VMs can send false ARP (IPv4) and ND (IPv6) messages, causing significant overloads in NVEs, NVO3 Gateways, and NVAs. The attacker can intercept, modify, or even stop data in-transit ARP/ND messages intended for other VNs and initiate DDOS attacks to other VMs attached to the same NVE. A simple black-hole attacks can be mounted by sending a false ARP/ND message to indicate that the victim's IP address has moved to the attacker's VM. That technique can also be used to mount man-in-the-middle attacks. Additional effort are required to ensure that the intercepted traffic can be eventually delivered to the impacted VMs.

The locator-identifier mechanism given as an example (ILA) doesn't include secure binding. It does not discuss how to securely bind the new locator to the identifier.

Because of those threats, VM management system needs to apply stronger security mechanisms when adding a VM to an NVE. Some tenants may have requirements that prohibit their VMs to be co-attached to the NVEs with other tenants. Some Data Centers deploy additional functionality in their NVO3 Gateways to mitigate the ARP/ND threats. These may include periodically sending each Gateway's ARP/ND cache contents to the NVA or other central control system. The objective is to identify the ARP/ND cache entries that are not consistent with the locations of VMs and their IP addresses indicated by the VM Management System.



## **11. IANA Considerations**

This document makes no request to IANA.

## **12. Acknowledgments**

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## **13. Change Log**

- . submitted version -00 as a working group draft after adoption
- . submitted version -01 with these changes: references are updated,
  - o added packets in flight definition to [Section 2](#)
- . submitted version -02 with updated address.
- . submitted version -03 to fix the nits.
- . submitted version -04 in reference to the WG Last call comments.
- . Submitted version - 05, 06, 07, 08, 09, 10, 11, 12, 13, 14 to address IETF LC comments from TSV area.

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