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Identifier-locator addressing for network virtualization
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Abstract

This specification describes identifier-locator addressing (ILA) in IPv6 for network virtualization. Identifier-locator addressing differentiates between location and identity of a network node. Part of an address expresses the immutable identity of the node, and another part indicates the location of the node which can be dynamic. Identifier-locator addressing can be used to efficiently implement overlay networks for network virtualization

Table of Contents

1 Introduction

This specification describes the data path, address formats, and expected use cases of identifier-locator addressing in IPv6 ([RFC2460]). The Identifier-Locator Network Protocol (ILNP) ([RFC6740], [RFC6741]) defines a protocol and operations model for identifier-locator addressing in IPv6. Many concepts here are taken from ILNP, however there are some differences in the context of network virtualization-- for instance in ILA a method to encode a virtual network identifier and virtual address within an identifier is defined.

In identifier-locator addressing, an IPv6 address is split into a locator and an identifier component. The locator indicates the topological location in the network for a node, and the identifier indicates the node's identity which refers to the logical or virtual

node in communications. Locators are routable within a network, but identifiers typically are not. An application addresses a destination by identifier. Identifiers are mapped to locators for transit in the network. The on-the-wire address is composed of a locator and an identifier: the locator is sufficient to route the packet to a physical host, and the identifier allows the receiving host to forward the packet to the addressed application.

Identifiers are not statically bound to a host on the network, and in fact their binding (or location) may change. This is the basis for network virtualization and address migration. An identifier is mapped to a locator at any given time, and a set of identifier to locator mappings is propagated throughout a network to allow communications. The mappings are kept synchronized so that if an identifier migrates to a new physical host, its identifier to locator mapping is updated.

In network virtualization, an identifier may further be split into a virtual network identifier and virtual host address. With identifier-locator addressing network virtualization can be implemented in an IPv6 network without any additional encapsulation headers. Packets sent with identifier-locator addresses look like plain unencapsulated packets (e.g. TCP/IP packets). This "encapsulation" is transparent to the network, so protocol specific mechanisms in network hardware work seamlessly. These mechanisms include hash calculation for ECMP, NIC large segment offload, checksum offload, etc.

ILA exhibits properties of different networking techniques:

- Network Address Translation
- Source routing
- Encapsulation

2 Motivation

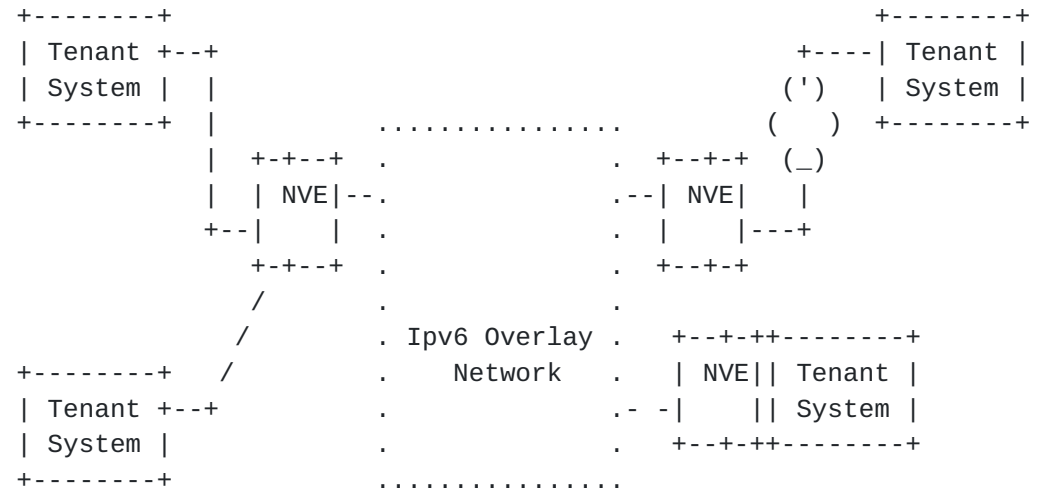
This section highlights the motivation for identifier-locator addressing.

2.1 Network virtualization

Identifier-locator addressing allows a data plane method to implement network virtualization without encapsulation and its related overheads. The service ILA provides is explicitly layer 3 over layer 3 network virtualization (IPv4 or IPv6 over IPv6).

2.1.1 Architecture

The architecture for Network Virtualization over Layer 3 ([NVO3ARCH]) can be applied to network virtualization with ILA.



A Network Virtualization Edge (NVE) [RFC7365] is the entity that implements the overlay functionality using ILA. An NVE resides at the boundary between a Tenant System and the IPV6 overlay network as shown above. An NVE creates and maintains local state about each Virtual Network for which it is providing service on behalf of a Tenant System.

As in traditional network virtualization, NVEs are responsible for transit of tenant's packets through the overlay network. With ILA, the NVEs perform address translation on packets as opposed to encapsulation. The ingress NVE will translate the virtual address of a destination to an ILA address. At the egress NVE, the reverse translation is performed.

2.1.2 Multi-tenant virtualization

Identifier-locator addressing may be used as an alternative to nvo3 encapsulation protocols (such as GUE [GUE]). In multi-tenant virtualization, overlay networks are established for various tenants to create virtual networks and a tenant's nodes are assigned virtual addresses. Virtual networking identifiers are used to encode a virtual network identifier and a virtual address in an ILA address.

An advantage of identifier-locator addressing is that the overhead of encapsulation is reduced and use of virtualization can be transparent to the underlying network. A downside is that some features that use additional data in an encapsulation aren't available (security option in GUE for instance [GUESEC]).

Identifier-locator addressing may be appropriate in network virtualization where the users are trusted, for instance if virtual networks were assigned to different departments within an enterprise. Network virtualization in this context provides a means of isolation of traffic belonging to different departments of a single tenant. In this scenario, if the isolation breaks and packets uintentionally crosses between virtual networks, it would not be considered a security risk.

2.2 Data center virtualization

A primary motivation for identifier-locator addressing is data center virtualization. Virtualization within a data center permits malleability and flexibility in using data center resources. In particular, identifier-locator addressing virtualizes networking to allow flexible job scheduling and possibility of live task migration.

2.2.1 Address per task

Managing the port number space for services within a data center is a nontrivial problem. When a service task is created, it may run on arbitrary hosts. The typical scenario is that the task will be started on some machine and will be assigned a port number for its service. The port number must be chosen dynamically to not conflict with any other port numbers already assigned to tasks on the same machine (possibly even other instances of the same service). A canonical name for the service is entered into a database with the host address and assigned port. When a client wishes to connect to the service, it queries the database with the service name to get both the address of an instance as well as its port number. Note that DNS is not adequate for the service lookup since it does not provide port numbers.

With ILA, each service task can be assigned its own IPv6 address and therefore will logically be assigned the full port space for that address. This a dramatic simplification since each service can now use a publicly known port number that does not need to unique between services or instances. A client can perform a lookup on the service name to get an IP address of an instance and then connect to that address using a well known port number. In this case, DNS is sufficient for directing clients to instances of a service.

Algorithms for the creation of unique address per task are described in Appendix A.

2.2.2 Job scheduling

In the usual data center model, jobs are scheduled to run as tasks on some number of machines. A distributed job scheduler provides the scheduling which may entail considerable complexity since jobs will often have a variety of resource constraints. The scheduler takes these constraints into account while trying to maximize utility of the data center in terms utilization, cost, latency, etc. Data center jobs do not typically run in virtual machines (VMs), but may run within containers. Containers are mechanisms that provide resource isolation between tasks running on the same host OS. These resources can include CPU, disk, memory, and networking.

A fundamental problem arises in that once a task for a job is scheduled on a machine, it often needs to run to completion. If the scheduler needs to schedule a higher priority job or change resource allocations, there may be little recourse but to kill tasks and restart them on a different machine. In killing a task, progress is lost which results in increased latency and wasted CPU cycles. Some tasks may checkpoint progress to minimize the amount of progress lost, but this is not a very transparent or general solution.

An alternative approach is to allow transparent job migration. The scheduler may migrate running jobs from one machine to another.

Under the orchestration of the job scheduler, the steps to migrate a job may be:

1) Stop running tasks for the job.
2) Package the run time state of the job. The run time state is derived from the containers for the jobs.
3) Send the run time state of the job to the new machine where the job is to run.
4) Instantiate the job's state on the new machine.
5) Start the tasks for the job continuing from the point at which it was stopped.

This model similar to virtual machine (VM) migration except that the run time state is typically much less data-- just task state as opposed to a full OS image. Task state may be compressed to reduce latency in migration.

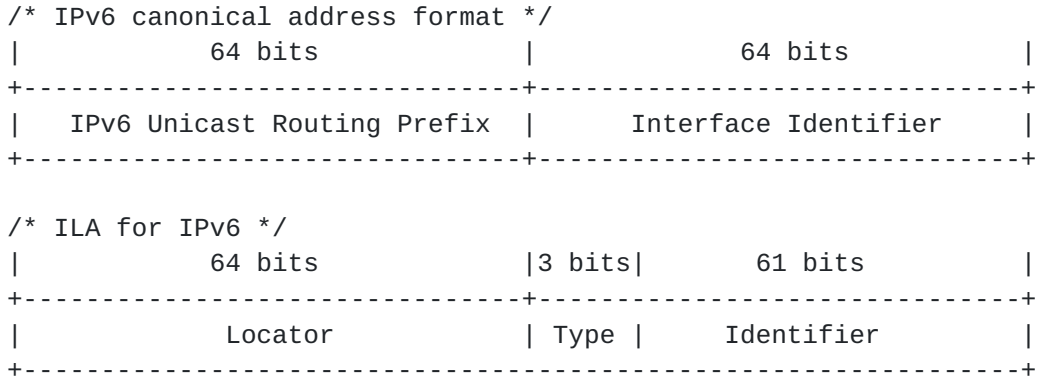
The networking state of interest to migrate are the addresses used by the task and open transport connections. The handling of these at task migration is discussed in Appendix B.

3 Address formats

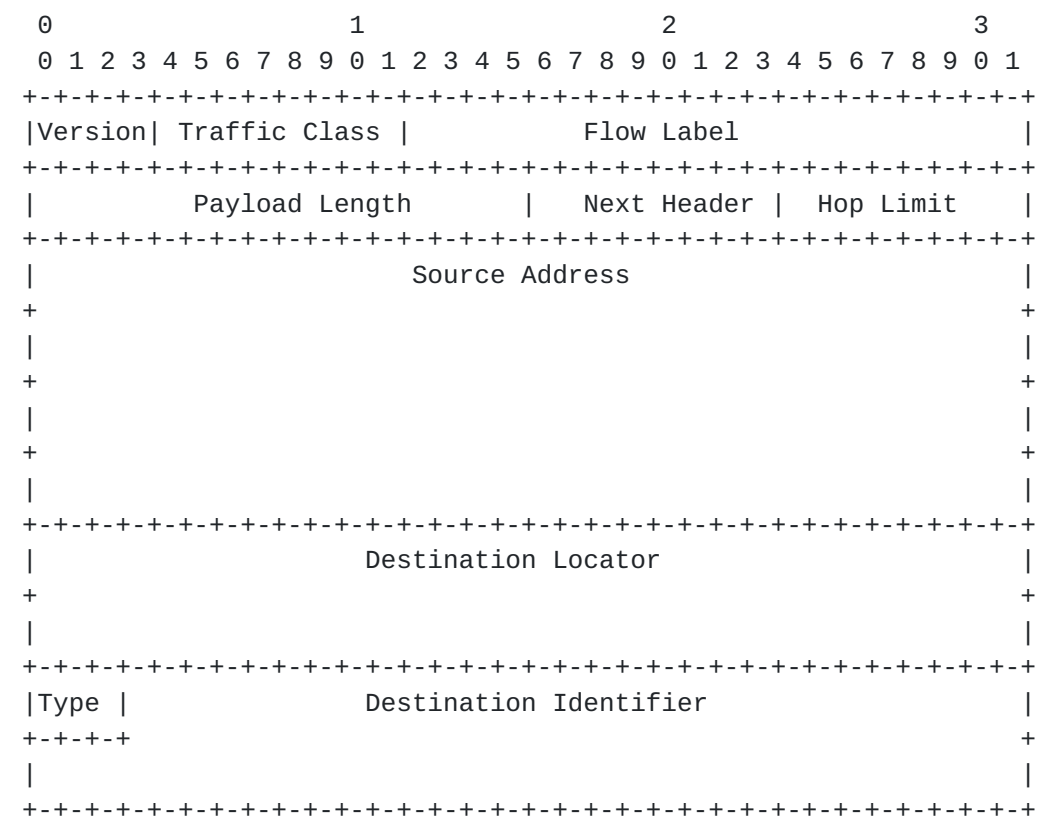
This section describes the address formats associated with identifier-locator addressing in network virtualization.

3.1 ILA format

As described in ILNP ([RFC6741]) an IPv6 address may be encoded to hold a locator and identifier where each occupies sixty-four bits. In ILA, the upper three bits of the identifier indicate an identifier type.



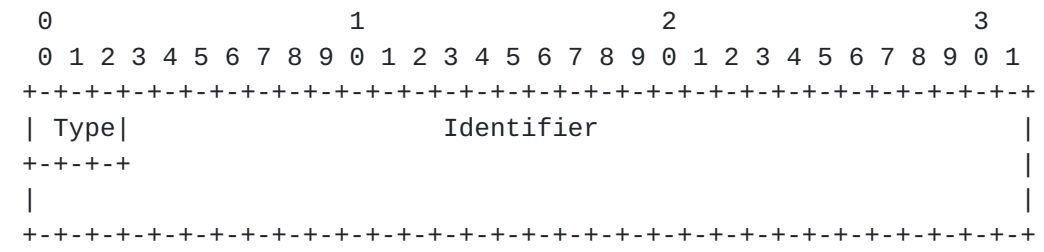
An IPv6 header with an ILA address would then have the format:



3.2 Identifier format

An ILA identifier includes a three bit type field and sixty-one bits for an identifier value.

/* Identifier format for ILA */



- Type: Type of the identifier (see below).

- Identifier: Identifier value.

3.3 Identifier types

Defined identifier types are:

0: interface identifier

1: locally unique identifier

2: virtual networking identifier for IPv4 address

3: virtual networking identifier for IPv6 unicast address

4: virtual networking identifier for IPv6 multicast address

5-7: Reserved

3.4 Interface identifiers

The interface identifier type indicates a plain local scope interface identifier. When this type is used the address is a normal IPv6 address without identifier-locator semantics. The pupose of this type is to allow normal IPv6 addresses to be defined within the same networking prefix as ILA addresses. The type bits must be zero, and the format of the other bits (subnetting) would be site-defined. For example, the format of an interface identifer might be:

```
/* Local scope interface identifier */
|         64 bits            |3 bits|       61 bits             |
+----------------------------+------+---------------------------+
|          Prefix            |  0x0 |         IID               |
+-------------------------------------------------------------+
```

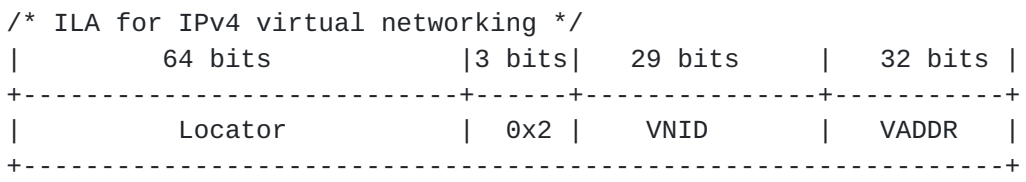
3.5 Locally unique identifiers

Locally unique identifiers (LUI) can be created for various addressable nodes within a network. These identifiers are in a flat sixty-one bit space and must be unique within a domain (unique within a site for instance). To simplify administration, hierarchical allocation of locally unique identifiers may be performed.

```
/* ILA with locally unique identifiers */
|         64  bits           |3 bits|         61 bits           |
+----------------------------+------+---------------------------+
|          Locator           |  0x1 |   Locally unique ident.   |
+-------------------------------------------------------------+
```

3.6 Virtual networking identifiers for IPv4

This type defines a format for encoding an IPv4 virtual address and virtual network identifier within an identifier.



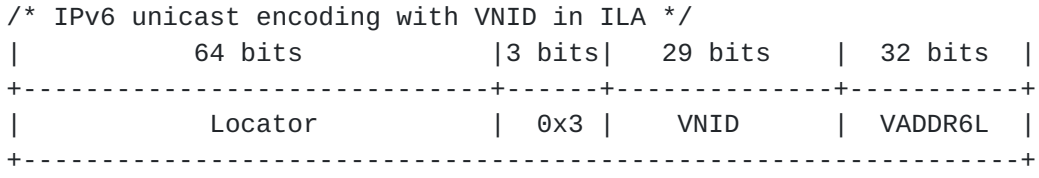
VNID is a virtual network identifier and VADDR is a virtual address within the virtual network indicated by the VNID. The VADDR can be an IPv4 unicast or multicast address, and may often be in a private address space (i.e. [RFC1918]) used in the virtual network.

3.7 Virtual networking identifiers for IPv6

A virtual network identifier and an IPv6 virtual host address (tenant visible address) can be encoded within an identifier. Encoding the virtual host address involves mapping the 128 bit address into a sixy-one bit identifier. Different encodings are used for unicast and multicast addresses.

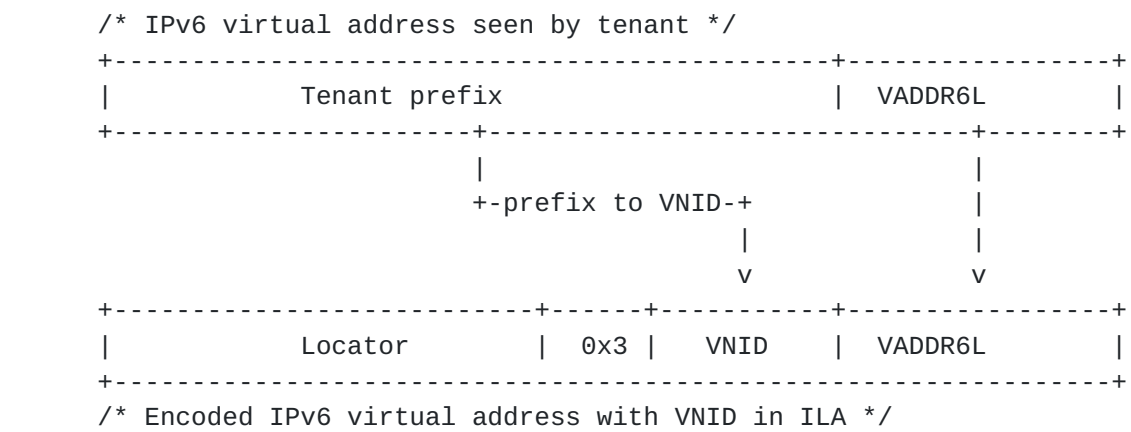
3.7.1 Virtual networking identifiers for IPv6 unicast

In this format, the virtual network identifier and virtual IPv6 unicast address are encoded within an identifier. To facilitate encoding of virtual addresses, there is a unique mapping between a VNID and a ninety-six bit prefix of the virtual address.

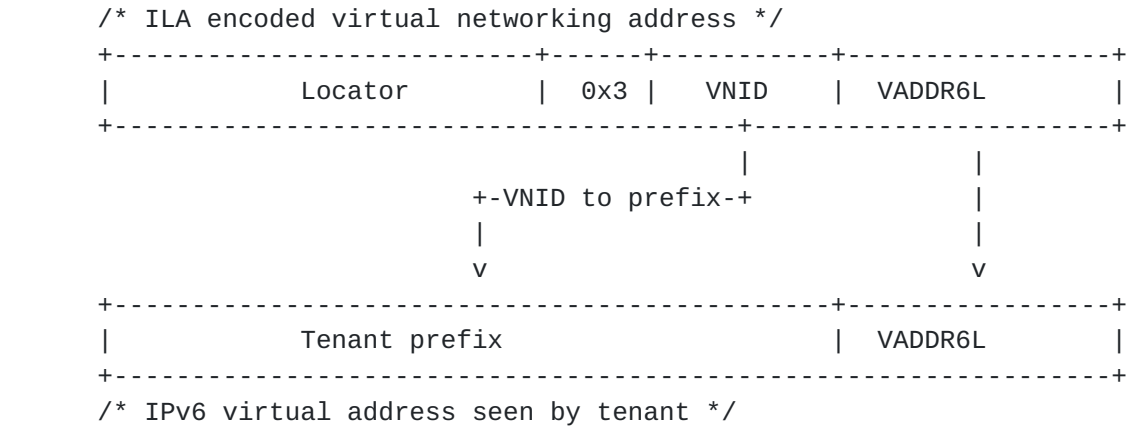


VADDR6L contains the low order 32 bits of the IPv6 virtual address. The upper 96 bits of the virtual address inferred from the VNID to prefix mapping.

The figure below illustrates encoding a tenant IPv6 virtual unicast address into a ILA address.

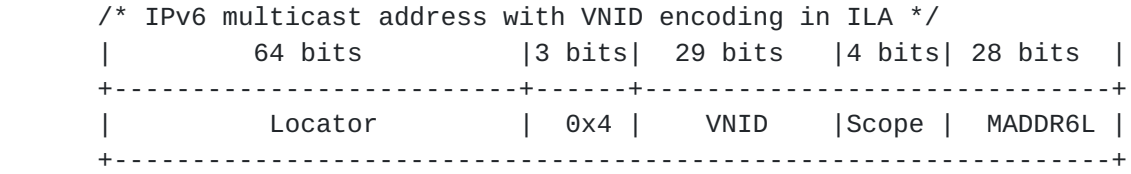


This encoding is reversible, given an ILA address, the virtual address visible to the tenant can be deduced:



3.7.2 Virtual networking identifiers for IPv6 multicast

In this format, a virtual network identifier and virtual IPv6 multicast address are encoded within an identifier.



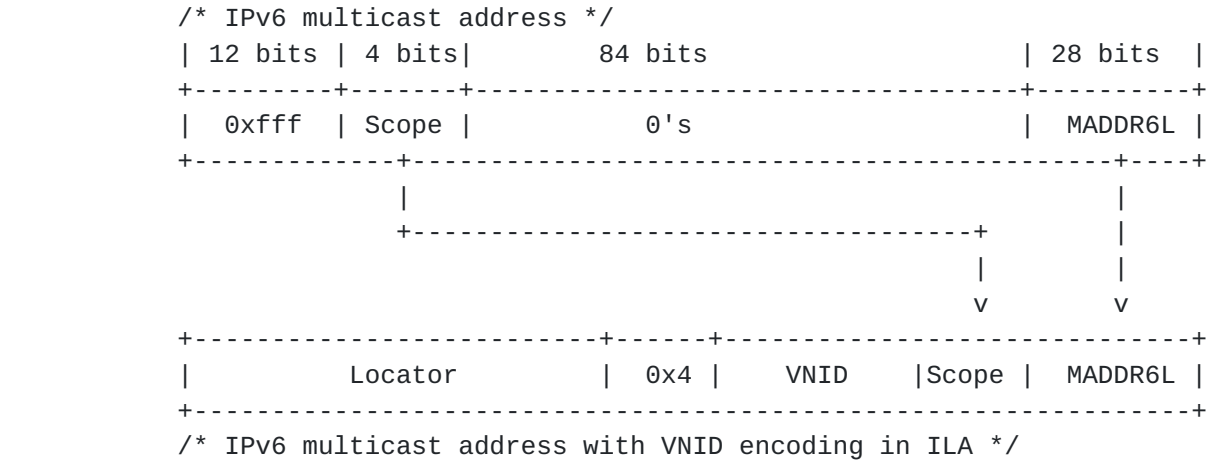
This format encodes an IPv6 multicast address in an identifier. The scope indicates multicast address scope as defined in [RFC7346]. MADDR6L is the low order 28 bits of the multicast address. The full multicast address is thus:

ff0<Scope>::0<MADDRL6 high 12 bits>:<MADDRL6 low 16 bits>

And so can encode multicast addresses of the form:

ff0X::0 to ff0X::0fff:ffff

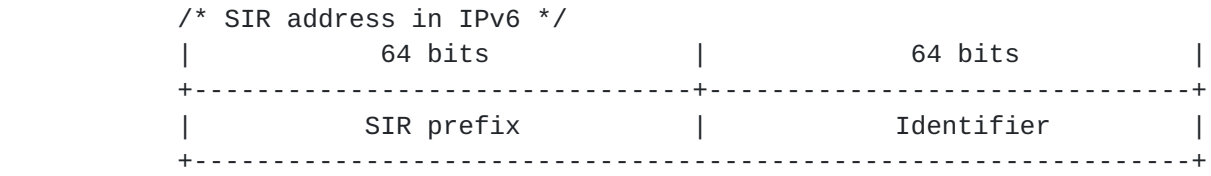
The figure below illustrates encoding a tenant IPv6 virtual multicast address into an ILA address.



3.8 Standard identifier representation addresses

An identifier serves as the external representation of a network node. For instance, an identifier may refer to a specific host, virtual machine, or tenant system. When a host initiates a connection or sends a packet, it uses the identifier to indicate the peer endpoint of the communication. The endpoints of an established connection context also nominally refer to identifiers. It is only when the packet is actually being sent over a network that the locator for the identifier needs to be resolved.

In order to maintain compatibility with existing networking stacks and applications, identifiers are encoded in IPv6 addresses using a standard identifier representation (SIR) address. A SIR address is a combination of a prefix which occupies what would be the locator portion of an ILA address, and the identifier in its usual location.



A SIR prefix may be site-local, or globally routable. A globally routable SIR prefix facilitates connectivity between hosts on the Internet and ILA endpoints. A gateway between a site's network and the Internet can translate between SIR prefix and locator for an

identifier. A network may have multiple SIR prefixes, and may also allow tenant specific SIR prefixes in network virtualization. Note that if there are multiple SIR prefixes they would share the same identifier space.

The standard identifier representation address can be used as the externally visible address for a node. This can used throughout the network, returned in DNS AAAA records ([RFC3363]), used in logging, etc. An application can use a SIR address without knowledge that it encodes an identifier.

3.8.1 SIR for locally unique identifiers

The SIR address for a locally unique identifier has format:

```
/* SIR address with locally unique identifiers */
|            64  bits            |3 bits|         61 bits        |
+---------------------------------+------+------------------------+
|           SIR prefix            |  0x1 |  Locally unique ident. |
+-------------------------------------------------------------------+
```

When using ILA with locally unique identifiers a flow tuple logically has the form:

```
(source identifier, source port,
 destination identifier, destination port)
```

Using standard identifier representation the flow is then represented with IPv6 addresses:

```
(source SIR address, source port,
 destination SIR address, destination port)
```

3.8.2 SIR for virtual addresses

An ILA virtual address may be encoded using the standard identifier representation. For example, the SIR address for an IPv6 virtual address may be:

```
/* SIR with IPv6 virtual network encoding */
|           64 bits             |3 bits| 29 bits     |  32 bits   |
+-------------------------------+------+-------------+------------+
|     Tenant's SIR prefix       |  0x3 |    VNID     |  VADDRL6   |
+-------------------------------------------------------------------+
```

In a tenant system, a flow tuple would have the form:

```
(local VADDR, local port, remote VADDR, remote port)
```

After translating packets for the flow into ILA, the flow would be identified on-the-wire as:

((local VNID, local VADDR), local port,
(remote VNID, remote VADDR), remote port

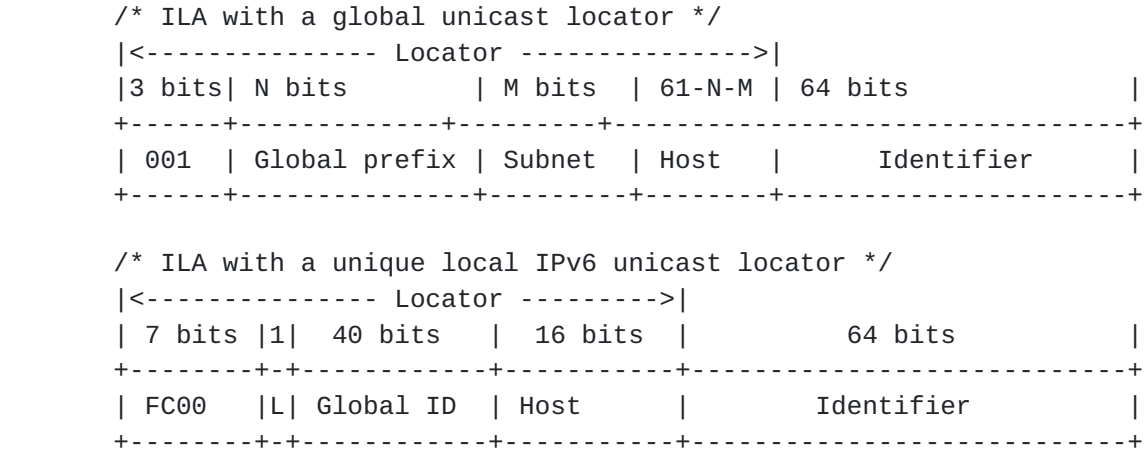
A tenant may communicate with a peer in the network which is not in its virtual network, for instance to reach a network service (see below). In this case the flow tuple at the peer may be:

(local SIR address, local port,
remote SIR address, remote port)

In this example, the remote SIR address is a SIR address for a virtual networking identifier, however from peer's connectivity perspective this is not distinguishable from a SIR address with a locally unique identifier or even a non-ILA address.

3.9 Locators

Locators are routable network address prefixes that address physical hosts within the network. They may be assigned from a global address block [RFC3587], or be based on unique local IPv6 unicast addresses as described in [RFC4193].



4 Operation

This section describes operation methods for using identifier-locator addressing with network virtualization.

4.1 Identifier to locator mapping

An application initiates a communication or flow using a SIR address or virtual address for a destination. In order to send a packet on

the network, the destination identifier is mapped to a locator. The mappings are not expected to change frequently, so it is likely that locator mappings can be cached in the flow contexts.

Identifier to locator mapping is nearly identical to the mechanism needed in virtual networking to map a virtual network and virtual host address to a physical host. These mechanisms should leverage a common solution.

The mechanisms of propagating and maintaining identifier to locator mappings are outside the scope of this document.

4.2 Address translations

With ILA, address translation is performed to convert SIR addresses to ILA addresses, and ILA addresses to SIR addresses. Translation is done on a destination address as a form of source routing.

4.2.1 SIR to ILA address translation

When transmitting a packet, the locator for the destination ILA address might need to be set before the packet is sent on the wire. In the case that packet was created using a standard identifier representation, the SIR prefix is overridden with a locator. Since this operation is potentially done for every packet the process should be very efficient. Presumably, a host will maintain a cache of identifier locator mappings with a fast lookup function. If there is a connection state associated with the communication, the locator information may be cached with the connection state to obviate the need to perform a lookup per packet.

The typical steps to transmit a packet using ILA are:

1) Stack creates a packet with source address set to a SIR address for the local identity, and the destination address is set to the SIR address for the peer. The peer SIR address may have been discovered through DNS or other means.

2) Stack overwrites the SIR prefix in the destination address with a locator for the peer. This locator is discovered by a lookup in the locator to identifier mappings.

3) If a transport checksum includes a pseudo header that covered the original addresses, the checksum needs to be updated accordingly.

4) Packet is sent on the wire. The network routes the packet to the host indicated by the locator.

4.2.2 ILA to SIR address translation

Upon reception, an ILA address must be translated back to a SIR address before upper layer processing.

Receive processing may be:

1) Packet is received, the destination locator matches an interface address prefix on the host.

2) A lookup is performed on the destination identifier to find if it addresses a local identifier. If match is found, a SIR address can be created for the destination (overwrite locator with a SIR prefix).

3) Perform any checks as necessary. Validate locators, identifiers, and check that packet is not illegitimately crossing virtual networks (see below).

4) Forward packet to application processing. If necessary, the addresses in the packet can be converted to SIR addresses in place. Changing the addresses may also entail updating the checksum to reflect that (similar to a NAT translation).

4.3 Virtual networking operation

When using ILA with virtual networking identifiers, address translation is performed to convert tenant virtual network and virtual addresses to ILA addresses, and ILA addresses back to a virtual network and tenant's virtual addresses. Address translation is performed similar to the SIR translation cases described above.

4.3.1 Crossing virtual networks

With explicit configuration, virtual network hosts may communicate directly with virtual hosts in another virtual network by using SIR addresses for virtualization in both the source and destination addresses. This might be done to allow services in one virtual network to be accessed from another (by prior agreement between tenants).

4.3.2 IPv4/IPv6 protocol translation

An IPv4 tenant may send a packet that is converted to an IPv6 packet with ILA addresses having IPv4 virtual networking identifiers. Similarly, an IPv6 packet with ILA addresses may be converted to an IPv4 packet to be received by an IPv4-only tenant. These are IPv4/IPv6 stateless protocol translations as described in [RFC6144]

and [RFC6145].

4.4 Checksum handling

TCP and UDP checksums include a pseudo header checksum that covers the IP addresses in a packet. In the case of identifier-locator addressing the checksum must include the actual addresses set in the packet on the wire. So when creating a checksum for transmit, or verifying a checksum on receive, identifier-locator addressing must be taken into account.

4.4.1 Transmit checksum

If the source and destination locators are available when the transport checksum is being set, these can be used to calculate the pseudo checksum for the packet. This might be applicable in cases where locator information is cached within the context for a transport connection.

If the locators are set after the transport layer processing, the checksum can be updated following NAT procedures for address translation.

4.4.2 Receive checksum

Similar to the transmit case, if address translation occurs before transport layer processing the checksum must be adjusted per NAT. An implementation may verify a transport checksum before converting addresses to standard identifier representation to potentially obviate modifying the transport checksum to account for translation.

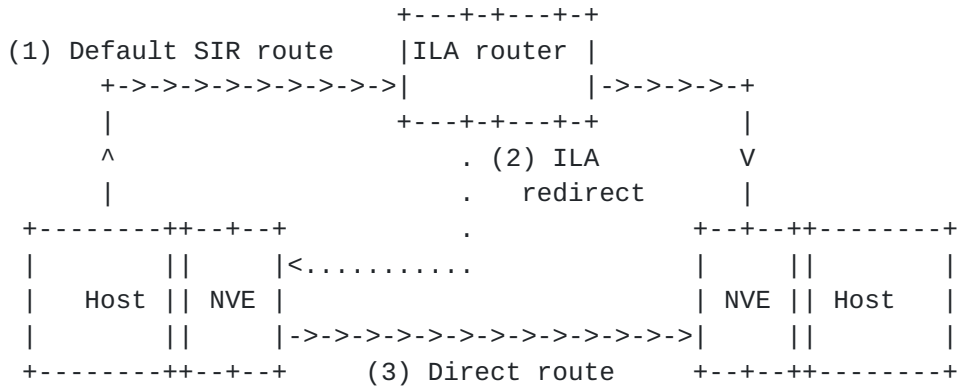
4.5 Address selection

There may be multiple possibilities for creating either a source or destination address. A node may be associated with more than one identifier, and there may be multiple locators for a particular identifier. The selection of an identifier occurs at flow creation and must be invariant for the duration of the flow. Locator selection should be done once per flow, however may change (in the case of a migrating connection it will change). ILA address selection should follow guidelines in Default Address Selection for Internet Protocol Version 6 (IPv6) ([RFC6724]).

4.6 SIR address routing

ILA is intended to be sufficiently lightweight so that all the hosts in a data center could potentially send and receive ILA addressed packets. In order to scale this model and allow for hosts that do not

participate in ILA, a routing topology may be applied. A simple topology is illustrated below.



An ILA router is a node that implements both NVE and NVA (Network Virtulization Authority). When an ILA router receives a SIR addressed packet it will perform the ILA translation and send the ILA addressed packet to the destination NVE.

Host NVEs might not be initialized with ILA identifier to locator mappings. When a host sends a SIR addressed packet, the packet is routed to an ILA router based on the SIR prefix. The ILA router provides ILA translation for the SIR prefix (this is shown in (1) above). In addition to forwarding the ILA packet, the ILA router may send an "ILA redirect" back to the source (at (2) above). The redirect indicates the locator to use for the associated identifier. Subsequently, the NVE at the source host can perform ILA translation to send directly to the destination NVE thus eliminating triangular routing (as shown in (3)). The specification of the ILA redirect message is outside the scope of this document.

4.7 Duplicate identifier detection

As part of implementing the locator to identifier mapping, duplicate identifier detection may be implemented in a centralized control plane. A registry of identifiers could be maintained (possibly in association the identifier to locator mapping database). When a node creates an identifier it registers the identifier, and when the identifier is no longer in use (e.g. task completes) the identifier is unregistered. The control plane should able to detect a registration attempt for an existing identifier and deny the request.

5. Communication scenarios

This section describes the use of identifier-locator addressing in several scenarios.

5.1 Terminology

A formal notation for identifier-locator addressing with ILNP is described in [RFC6740]. We extend this to include for network virtualization cases.

Basic terms are:

A = IP Address
I = Identifier
L = Locator
LUI = Locally unique identifier
VNI = Virtual network identifier
VA = An IPv4 or IPv6 virtual address
VAX = An IPv6 networking identifier (IPv6 VA mapped to VAX)
SIR = Prefix for standard identifier representation
VNET = IPv6 prefix for a tenant (assumed to be globally routable)
Iaddr = IPv6 address of an Internet host

An ILA IPv6 address is denoted by

L:I

A transport endpoint IPv6 address with a locally unique identifier with SIR prefix is denoted by

SIR:LUI

A virtual identifier with a virtual network identifier and a virtual IPv4 address is denoted by

VNI:VA

An ILA IPv6 address with a virtual networking identifier for IPv4 would then be denoted

L:(VNI:VA)

The local and remote address pair in a packet or endpoint is denoted

A,A

An address translation sequence from transport visible addresses to ILA addresses for transmission on the network and back to transport endpoint addresses at the receiver has notation:

A,A -> L:I,A -> A,A

5.2 Identifier objects

Identifier-locator addressing is broad enough in scope to address many different types of networking objects within a data center. For descriptive purposes we classify these objects as tasks or tenant systems.

A task is a unit of execution that runs in the data center networks. These do not run in a virtual machine, but typically run in the native host context perhaps within containers. Tasks are the execution mechanism for native jobs in the data center.

A network service is a task that provides some network wide service such as DNS, remote storage, remote logging, etc. A network service may be accessed by tenant systems as well as other tasks.

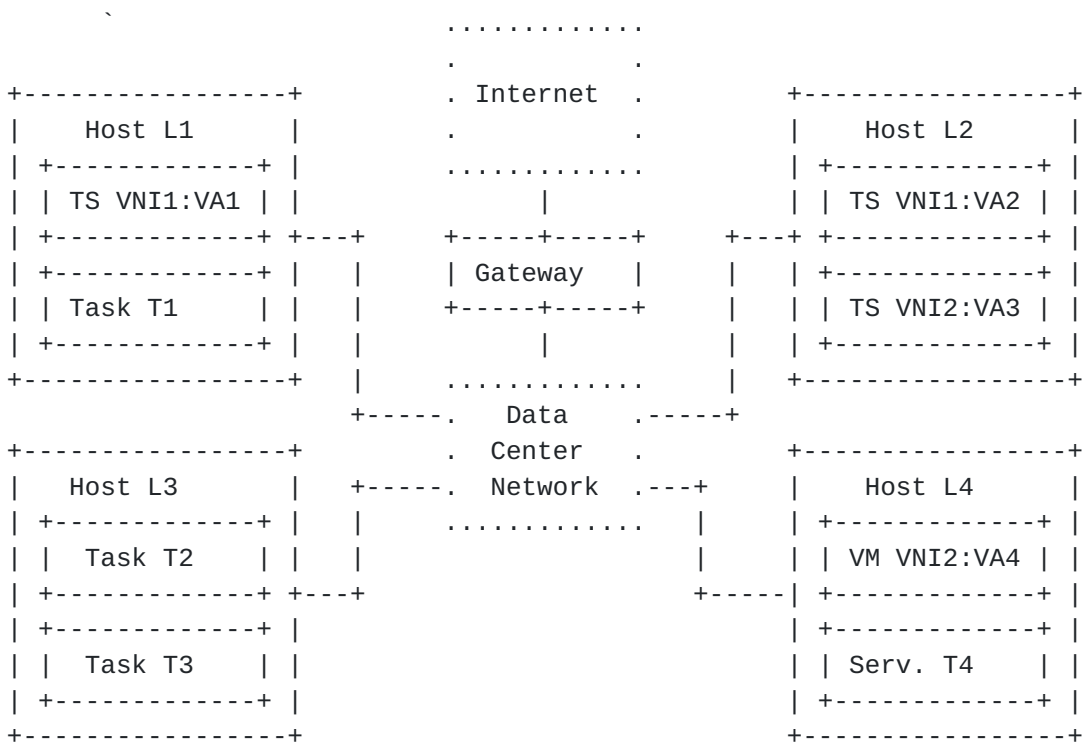
A tenant system, or TS, is a unit of execution which runs on behalf of a tenant in network virtualization. A TS may be implemented as a virtual machine or possibly using containers mechanisms. In either case, a virtual overlay network is implemented on behalf of a tenant, and isolation between tenants' virtual networks is paramount.

5.3 Reference network for scenarios

Several communication scenarios can be considered:

1) Task to task (service)
2) Task to Internet
3) Internet to task
4) TS to service
5) Task to TS
6) TS to Internet
7) Internet to TS
8) IPv4 TS to service
9) TS to TS in same virtual network using IPv6
10) TS to TS in same virtual network using IPv4
11) TS to TS in different virtual network using IPv6
12) TS to TS in different virtual network using IPv4
13) IPv4 TS to IPv6 TS in different virtual networks

The figure below provides an example network topology with ILA addressing in use. In this example, there are four hosts in the network with locators L1, L2, L3, and L4. There three tasks with identifiers T1, T2, and T3, as well as a networking service task with identifier T4. The identifiers for these tasks may be locally unique identifiers. There are two virtual networks VNI1 and VNI2, and four tenant systems addressed as: VA1 and VA2 in VNI1, VA3 and VA4 in VNI2. The network is connected to the Internet via a gateway.



5.4 Scenario 1: Task to task

The transport endpoints for task to task communication are the SIR addresses for the tasks. When a packet is sent on the wire, the locator is set in the destination address of the packet. On reception the destination addresses is converted back to SIR representation for processing at the transport layer.

If task T1 is communicating with task T2, the ILA translation sequence would be:

```
SIR:T1,SIR:T2 ->                    // Transport endpoints on T1
SIR:T1,L3:T2 ->                     // ILA used on the wire
SIR:T1,SIR:T2                       // Received at T2
```

5.5 Scenario 2: Task to Internet

Communication from a task to the Internet is accomplished through use of a SIR address (globally routable) in the source address of packets. No ILA translation is needed in this path.

If task T1 is sending to an address Iaddr on the Internet, the packet addresses would be:

```
SIR:T1,Iaddr
```

5.6 Scenario 3: Internet to task

An Internet host transmits packet to a task using an externally routable SIR address. The SIR prefix routes the packet to a gateway for the data center. The gateway translates the destination to an ILA address.

If a host on the Internet with address Iaddr sends a packet to task T3, the ILA translation sequence would be:

```
Iaddr,SIR:T3 ->                    // Transport endpoint at Iaddr
Iaddr,L1:T3 ->                     // On the wire in data center
Iaddr,SIR:T3                       // Received at T3
```

5.7 Scenario 4: TS to service task

A tenant can communicate with a data center service using the SIR address of the service.

If TS VA1 is communicating with service task T4, the ILA translation sequence would be:

```
VNET:VA1,SIR:T4->                  // Transport endpoints in TS
VNET:VA1,L3:T4->                   // On the wire
VNET:VA1,SIR:T4                    // Received at T4
```

Where VNET is the address prefix for the tenant.

Note that from the point of view of the service task there is no material difference between a peer that is a tenant system versus one which is another task.

5.8 Scenario 5: Task to TS

A task can communicate with a TS through it's externally visible address.

If task T2 is communicating with TS VA4, the ILA translation sequence would be:

```
SIR:T2,VNET:VA4 ->                 // Transport endpoints at T2
SIR:T2,L4:(VNI2:VAX4) ->           // On the wire
SIR:T2,VNET:VA4                    // Received at TS
```

5.9 Scenario 6: TS to Internet

Communication from a TS to the Internet assumes that the VNET for the TS is globally routable, hence no ILA translation would be needed.

If TS VA4 sends a packet to the Internet, the addresses would be:

```
VNET:VA4,Iaddr
```

5.10 Scenario 7: Internet to TS

An Internet host transmits a packet to a tenant system using an externally routable tenant prefix and address. The prefix routes the packet to a gateway for the data center. The gateway translates the destination to an ILA address.

If a host on the Internet with address Iaddr is sending to TS VA4, the ILA translation sequence would be:

```
Iaddr,VNET:VA4 ->                  // Endpoint at Iaddr
Iaddr,L4:(VNI2:VAX4) ->            // On the wire in data center
Iaddr,VNET:VA4                     // Received at TS
```

5.11 Scenario 8: IPv4 TS to service

A TS that is IPv4-only may communicate with a data center network service using protocol translation. The network service would be represented as an IPv4 address in the tenant's address space, and stateless NAT64 should be usable as described in [RFC6145].

If TS VA2 communicates with service task T4, the ILA translation sequence would be:

```
VA2,ADDR4 ->                       // IPv4 endpoints at TS
SIR:(VNI1:VA2),L4:T4 ->            // On the wire in data center
SIR:(VNI1:VA2),SIR:T4              // Received at task
```

VA2 is the IPv4 address in the tenant's virtual network, ADDR4 is an address in the tenant's address space that maps to the network service.

The reverse path, task sending to a TS with an IPv4 address, requires a similar protocol translation.

For service task T4 to communicate with TS VA2, the ILA translation sequence would be:

```
SIR:T4,SIR:(VNI1:VA2) ->           // Endpoints at T4
SIR:T4,L2:(VNI1:VA2)   ->          // On the wire in data center
ADDR4,VA2                          // IPv4 endpoint at TS
```

5.12 TS to TS in the same virtual network

ILA may be used to allow tenants within a virtual network to communicate without the need for explicit encapsulation headers.

5.12.1 Scenario 9: TS to TS in same VN using IPV6

If TS VA1 sends a packet to TS VA2, the ILA translation sequence would be:

```
VNET:VA1,VNET:VA2 ->                // Endpoints at VA1
VNET:VA1,L2:(VNI1,VAX2) ->          // On the wire
VNET:VA1,VNET:VA2 ->                // Received at VA2
```

5.12.2 Scenario 10: TS to TS in same VN using IPv4

For two tenant systems to communicate using IPv4 and ILA, IPv4/IPv6 protocol translation is done both on the transmit and receive.

If TS VA1 sends an IPv4 packet to TS VA2, the ILA translation sequence would be:

```
VA1,VA2 ->                          // Endpoints at VA1
SIR:(VNI1:VA1),L2:(VNI1,VA2) ->     // On the wire
VA1,VA2                             // Received at VA2
```

5.13 TS to TS in a different virtual networks

A tenant system may be allowed to communicate with another tenant system in a different virtual network. This should only be allowed with explicit policy configuration.

5.13.1 Scenario 11: TS to TS in a different VNs using IPV6

For TS VA4 to communicate with TS VA1 using IPv6 the translation sequence would be:

```
VNET2:VA4,VNET1:VA1->               // Endpoint at VA4
VNET2:VA4,L1:(VNI1,VAX1)->          // On the wire
VNET2:VA4,VNET1:VA1                 // Received at VA1
```

Note that this assumes that VNET1 and VNET2 are globally routable between the two virtual networks.

5.13.2 Scenario 12: TS to TS in a different VNs using IPv4

To allow IPv4 tenant systems in different virtual networks to communicate with each other, an address representing the peer would

be mapped into the tenant's address space. IPv4/IPv6 protocol translation is done on transmit and receive.

For TS VA4 to communicate with TS VA1 using IPv4 the translation sequence may be:

```
VA4,SADDR1 ->                          // IPv4 endpoint at VA4
SIR:(VNI2:VA4),L1:(VNI1,VA1)->         // On the wire
SADDR4,VA1                             // Received at VA1
```

SADDR1 is the mapped address for VA1 in VA4's address space, and SADDR4 is the mapped address for VA4 in VA1's address space.

5.13.3 Scenario 13: IPv4 TS to IPv6 TS in different VNs

Communication may also be mixed so that an IPv4 tenant system can communicate with an IPv6 tenant system in another virtual network. IPv4/IPv6 protocol translation is done on transmit.

For VM VA4 using IPv4 to communicate with VM VA1 using IPv6 the translation sequence may be:

```
VA4,SADDR1 ->                          // IPv4 endpoint at VA4
SIR:(VNI2:VA4),L1:(VNI1,VAX1)->        // On the wire
SIR:(VNI2:VA4),SIR:(VNI1,VAX1)         // Received at VA1
```

SADDR1 is the mapped IPv4 address for VA1 in VA4's address space.

6 Security Considerations

Security must be considered when using identifier-locator addressing. In particular, the risk of address spoofing or address corruption must be addressed. To classify this risk the set possible destinations for a packet are classified as trusted or untrusted. The set of possible destinations includes those that a packet may inadvertently be sent due to address or header corruption.

If the set of possible destinations are trusted then packet misdelivery is considered relatively innocuous. This might be the case in a data center if all nodes were tightly controlled under single management. Identifier-locator addressing can be used in this case without further additional security.

If the set of possible destinations contains untrusted hosts, then packet misdelivery could be a risk. This may be the case that virtual machines with untrusted third party applications or OSes are running in the network. A malicious user may be snooping for misdelivered packets, or may attempt to spoof addresses. Identifier-locator

addressing should be used with stronger security and isolation mechanisms such as IPsec or GUESEC.

7 IANA Considerations

There are no IANA considerations in this specification.

8 References

8.1 Normative References

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Appendix A: Task identifier generation

Potentially every task in a data center could be migratable as long as each task is assigned a unique identifier. Since an ILA identifier is sixty-one bits it is conceivable that identifiers could be allocated using a shared counter or based on a timestamp.

A.1 Globally unique identifiers method

For small to moderate sized deployments the technique for creating locally assigned global identifiers described in [RFC4193] could be used. In this technique a SHA-1 digest of the time of day in NTP format and an EUI-64 identifier of the local host is performed. N bits of the result are used as the globally unique identifier.

The probability that two or more of these IDs will collide can be approximated using the formula:

```
P = 1 - exp(-N**2 / 2**(L+1))
```

where P is the probability of collision, N is the number of identifiers, and L is the length of an identifier.

The following table shows the probability of a collision for a range of identifiers using a 61-bit length.

Identifiers	Probability of Collision
1000	2.1684*10^-13
10000	2.1684*10^-11
100000	2.1684*10^-09
1000000	2.1684*10^-07

Note that locally unique identifiers may be ephemeral, for instance a task may only exist for a few seconds. This should be considered when determining the probability of identifier collision.

A.2 Universally Unique Identifiers method

For larger deployments, hierarchical allocation may be desired. The techniques in Universally Unique Identifier (UUID) URN ([RFC4122]) can be adapted for allocating unique task identifiers in sixty-one bits. An identifier is split into two components: a registrar prefix and sub-identifier. The registrar prefix defines an identifier block which is managed by an agent, the sub-identifier is a unique value within the registrar block.

For instance, each host in a network could be an agent so that a task identifier could be created on the host that initially runs a task. The identifier might be composed of a twenty-four bit host identifier followed by a thirty-seven bit timestamp. Assuming that a host can start up to 100 tasks per second, this allows 43.5 years before wrap around.

```
/* Task identifier with host registrar and timestamp  */
|3 bits|     24 bits       |               37  bits              |
+------+-------------------+-------------------------------------+
| 0x1  |  Host identifier  |        Timestamp Identifier         |
+-------------------------------------------------------------------+
```

Appendix B: Task migration considerations

B.1 Address migration

ILA facilitates address (specifically identifier) migration between hosts as part of task migration or for other purposes. The steps in migrating an address might be:

1) Configure address on the target host.

2) Suspend use of the address on the old host. This includes handling established connections (see next section). A state may be established to drop packets or send an ILA redirect when packets to the migrated address are received.

3) Update the identifier to locator mapping database. Depending on the control plane implementation this may include pushing the new mapping to hosts.

4) Communicating hosts will learn of the new mapping via a control plane either by participation in a protocol for mapping propagation or by the ILA redirect mechanism.

B.2 Connection migration

When a task and its addresses are migrated between machines, the disposition of existing TCP connections needs to be considered.

The simplest course of action is to drop TCP connections across a migration. Since migrations should be relatively rare events, it is conceivable that TCP connections could be 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 may be viable.

For seamless migration, open connections may be migrated between hosts. Migration of these entails pausing the connection, packaging connection state and sending to target, instantiating 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 should 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 should either silently drop the packet or forward it to the new location.

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