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# Enabling Network Identifier (NI) in Information Centric Networks to Support Optimized Forwarding
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## Abstract

The objective of this proposal is to introduce the notion of network identifier (NI) in the ICN architecture. This is in addition to the existing names (i.e., content identifiers, CIs, or application identifiers, AIs, in general) that are currently used for both naming and routing/forwarding purposes. Network identifiers are needed considering the requirements on future networking architectures such as: (i) to support persistent names (or persistently named objects) and large-scale and high-speed mobility of any network entity (i.e, devices, services, and content), (ii) to accommodate different types of Internet of Things (IoT) services, many of which require low-latency performance, and enabling edge computing to support service virtualization, which will require support for large scale migration and replication of named resources, and (iii) to scale the ICN architecture to future Internet scale considering the exponentially increasing named entities. These considerations also require enabling a network based name resolution service for efficient and scalable routing.

In the current draft, we begin by highlighting the issues associated with ICN networking when utilizing only the AIs, which include persistently named content, services, and devices. Next we discuss the function NI serves, and provide a discussion on the two current NI-based proposals, along with their scope and functionalities. This is with the objective of having a single NI construct for ICN that is flexible enough to adapt to different networking contexts.

## Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

## Status of This Memo



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## 1. Introduction

Information centric networking (ICN) is proposed as a future Internet architecture to evolve the current host-centric design of Internet towards a content-oriented one, where the named object becomes the principle entity in networking. In doing so, contents, services, and devices become disentangled from location allowing for efficient use of the distributed in-network caches and compute resources with more flexible and dynamic packet forwarding techniques. ICN is expected to offer a scalable and secure networking solution to address many challenges of the current IP architecture. Towards this, we propose to formalize the notion of network identifier (NI) in ICN protocol, that is separate from content name or application identifier (CI/AI, or simply AI) used to both name resources and route user requests.

## 2. Application Identifier (AI) vs. Network Identifier (NI) in ICN

AI represent the names of service, content, or devices assigned by the application providers or device manufacturers, and which can be validated through appropriate security mechanisms. ICN should provide flexibility in accommodating a broad set of identifiers, within which the two well-known classes include hierarchical and flat identifiers. While a hierarchical identifier provides contextual richness for the names, a flat identifier offers a fixed predictable overhead and variable security properties within a given context. Today, this identifier set is already in the order of billions (with hundreds of millions top-level domain names [VRSGN], and billions of second-level domain names). As tens of billions of devices are expected to join the network, this identifier set will be further augmented with the corresponding data objects significantly expanding its size. To decouple applications from the underlying network dynamics, identifiers are expected to be persistent within the scope of the application and its deployment.

NI provides a binding for the AI to the network, at a location and in a topology relevant manner. NI is managed by the network provider to name the routers, point of attachments, servers and end devices. In addition to ICN names, in an overlay deployment, NI could assume names of the underlay network as well, such as IP or Ethernet addresses. The growth of the NI space is proportional to the rate of growth of domain topology, the total number of AS, and the end points (if they are managed by the network), hence, being much slower than the rate of growth of the named resources in the AI space. Hence if the objective is to limit the size of the forwarding table and scale control plane, it is desirable to route requests on NIs, with the mapping between AI and NI is achieved in a scalable manner using a network based name resolution system.

Content-centric design used by ICN allows end hosts to make requests using any type of name supported by the applications, including hierarchical (human-readable or hash-based) identifiers (as considered by CCN, NDN[CCN] for both the client application use and the network use-for routing-), or fixed flat identifiers (as considered by MobilityFirst[MFRST] in the network for routing). We refer to an ICN architecture that supports any application naming format (i.e., human-readable or flat) within the network for routing as a non-restricted ICN architecture (as in CCN/NDN), whereas an ICN architecture with a fixed naming format for routing within the network as a restricted ICN architecture (as in MobilityFirst).

As packet forwarding in ICN utilizes names or identifiers (associated with contents, hosts, or services) which are typically managed by applications, thereby of persistent nature, using such names in packet forwarding introduces the following list challenges in regards to routing scalability and forwarding efficiency [NAMES].

o Using AI for Routing/Forwarding: Overloading an identifier as a locator can lead to unstable routing control and forwarding plane operations, particularly when replication and mobility of content or end points are taken into consideration. Applications typically construct names and replicate contents or services to optimize their delivery without any consideration towards network scalability or efficiency. Hence name aggregation does not help with scaling the routing and forwarding as originally imagined, and the cost of this would be quite significant in real world scenarios, as discussed in [NCMP]. Furthermore, it is also observed in [QCMP] that, in certain scenarios (such as content mobility), name-based forwarding approaches can operate more efficiently, if used in conjunction with address-assisted schemes such as DNS or anchor point based approaches like Mobile IP [RFC3220]. Additionally, when names are used for network reachability, more practical problems such as name-suffix hole may arise, as the content requests are forwarded towards non-existent caches [MDHT].

o Routing/Forwarding Scalability: Routing scalability is typically achieved by designing NIs with aggregate-able property, which is the case for the current IP architecture. However, having such feature in a non-restricted ICN architecture would lead to relinquishing the persistency of the names, along with its security binding such as trust, as the names would involve a topological component for scalability, which can also suggest resources to be renamed depending on, for instance, network or business specs or characteristics. When content names or application identifiers use a hierarchical identifier format, we observe scalability problems in control and data plane operations

[SFWD]. Such problems are caused by various factors. For instance, the explosive growth observed in namespaces can lead to a similar growth in routing/forwarding information base or table sizes [AFWD][SPIT][WPIT], even when namespace aggregation is enabled, to significantly limit the forwarding efficiency and forwarding capacity. If ICN routing with hierarchical naming is the accepted form of naming, name-aggregation is highly unlikely to achieve any practical scalability. This is because, naming ontology and assignment typically consider application objectives of contextualizing names, service and content placement and replication to better suit the consumers' needs without considering any network objectives on control and data plane efficiency and scalability.

- Handling Mobility, Migration, and Replication: The impact of namespace expansion on routing/forwarding performance is typically exacerbated with content mobility, or the use of multi-homing and resource replication due to diminished aggregate-ability [NCMP]. The authors in [QCMP] concludes that, as more than 20% of end hosts make more than 10 network address transitions every day, thereby suggesting that mobility should be considered as the norm rather than the exception. Furthermore, to achieve location independent routing based on AIs, each mobility event associated with a device or a popular content may trigger updates on up to 14% of Internet routers.

For the above reasons, restructuring the identifier to directly or indirectly contain a globally routable component becomes an important requirement, especially, to handle mobility at the network layer for architectures that do not restrict names or identifiers to any specific format. We can refer to such operation as the Application and Network identifier split (where the NI represents the globally routable component, and the AI represents the persistent name/identifier) which enables splitting of the namespace to support routable, persistent, and human-friendly names or identifiers. In such a framework, names would be divided accordingly, i.e., based on application binding (offering persistent names) vs. advertised network entities (in routing plane) to provide a more scalable routing architecture. For instance, a persistent name or identifier /Provider/Type/Name, which would be used to create secure content objects, can be published by multiple content distributors, where it would be mapped to different NIs, such as /Distributor/Region/Zone/Storage, to resolve content names or identifiers to specific infrastructure entities. The fundamental requirements with this form of splitting is no different than that of MobilityFirst [MFRST] or LISP [RFC6830], which is the requirement of a network based name resolution system to map the two namespaces.

So far, various approaches have been proposed to support the use of NI in ICN-based networking architectures, depending on how this information is structured and where it is placed within the Interest (which may also determine the structuring of Data packets). Next, we discuss these solutions by specifically focusing on label-based ICN forwarding [FWLDR][FWLRP][MAAS] and ICN-based Map-and-Encap [MPNCP][SNAMP] to provide a general guidance on the use of NI in information centric networks.

## 3. NI based ICN Forwarding

AI based routing is a feasible solution within certain contexts such as: (i) when resources are static and routing is limited to local area networks or local domains, such as access networks within the scalability considerations of the control and forwarding plane; (ii) in ad hoc situations where AI can be combined with suitable suffix filters to seek content of interest for the applications.

On the other hand, the use of NI becomes important in the following situations: (i) when the Interest packet goes outside the local domain, where routing on AI is optionally supported (i.e., routing scalability and efficiency seeks precedence); (ii) when the Interest enters a local domain, and the domain has specific knowledge of an NI associated with the resource inside its domain.

With the above considerations, with respect to end-to-end networking, NI is not a mandatory feature, but an optional one. However, as significant amount of user traffic fetches resources outside the requesting host’s local domain, it becomes crucial to provide architectural support for NI in an ICN protocol. So far, two solutions for NI in ICN, overall with the same objectives but serving different purposes, have been proposed. These include the forwarding-label proposal [FWLDR] and the Link Object described in [SNAMP]. We next summarize these proposals and discuss their differences.

### 3.1. Label based ICN forwarding

Label-based ICN forwarding provides NI capability by encoding a network address along with (optional) security binding attributes within an Interest packet to guide it towards a content source (which can be the Producer, a content repository or a cache). We refer to this label as the forwarding label [FWLDR], which can be offered as part of an ICN network service (such as a name resolution service with ICN APIs to register and resolve names). For the forwarding label, we have the following important considerations: (i) forwarding label, if present in the Interest packet, takes precedence (over AI) for routing, (ii) forwarding label is mutable in the sense that it can be swapped or removed by intermediate network elements in the network based on routing considerations within its domain. Here, forwarding labels are not limited to only the ICN names, but, in an overlay mode, they can also represent names from other transport layers as well, for instance, an IP address or a MAC address.

Forwarding label consists of multiple components, with the NI representing the locator information. Forwarding label is embedded within the Interest message at the edge router or the end point within certain trust considerations, if the namespace supports the use of an NI to reach a specific destination. For security reasons, edge routers can validate the label based on the trust context or ignore any label inserted by an ICN forwarder at the end hosts, by removing the inserted label if the forwarding on labels is not supported, or by swapping it with a new one depending on the feedback from the name resolution system. Such an approach requires no trust relationship among different domains, as each domain is capable of resolving content namespace to a target domain, and swapping the received label with one to which its resolves.

Forwarding label support for a namespace can be offered at a global scale (i.e., supported by all the domains) or a local scale (supported by a subset of the existing domains). For instance, some autonomous systems can prioritize forwarding solely based on the content names (or offer limited support for label-based forwarding on specific namespaces). In such case, forwarding labels can include additional service tag (or information on the associated service, for which the use of forwarding label might be supported in certain domains, such as towards mobility service) for routing packets on the supported domains. In doing so, we can strategically forward requests over domains that support such service to provide more deterministic service guarantees.

If forwarding label use is supported (or permitted) within a domain, by default, forwarding label is given preference over content identifiers for packet forwarding. In such case, to maximize the forwarding efficiency, additional mapping tables can be implemented at the edge or border ICN routers for quick longest-prefix matching (LPM) lookup on content names to determine a (or the) matching forwarding label(s), which can then be used by the router to perform LPM lookup on the FIB. As forwarding label typically represents a target domain or router, a single LPM lookup on the FIB may suffice to find the outgoing interface for the received Interest. This state can also be software-defined based on application requirements using an SDN based control plane.

### 3.2. Link-object based ICN forwarding

ICN-based Map-and-Encap utilizes link objects, which include information on how to retrieve content objects. For instance, link objects can represent domains that host the content object, or direction towards which the requests need to be forwarded to find a matching content object. Link objects consist of two optional headers: (i) a link header, which includes the potential directives that can be used for forwarding and is signed by the Producer to validate its authenticity during forwarding, and (ii) a delegation header, which is used to represent the link choice utilized by the previous forwarder. Since delegations may change at consecutive hops depending on the view of forwarders' network state and forwarding strategy, delegation header represents a variable component that can be altered during packet forwarding.

The role of link objects is mainly for guidance, to provide global routing support on locally defined or routable content identifiers. Hence, if link objects are implemented, they are consulted by the ICN enabled routers only when forwarding lookup on content identifiers returns no match on the forwarding information base.

### 3.3. Link Object vs. Forwarding Label

Next we list the major differences between a link object and a forwarding label.

- o Link objects are set by the end host's forwarding daemon with certain level of trust associated to it, restricting the link component to be immutable during forwarding. Forwarding labels are set by the ICN edge routers or the end-host applications, with the ability of network based management during Interest forwarding, allowing each domain to perform packet forwarding according to its administrative and service policies.

- o Forwarding label allows the use of trust association to bind AI to the NI depending on the context associated with its use, whereas for the link objects, trust relationship is established by default.

- o Another difference is related to the processing of forwarding label and link objects at the ICN routers. Link object is processed only if the router cannot find a matching FIB entry for the content identifier. On the other hand, forwarding label is processed before a content identifier, if its use is enabled.

- o Forwarding label can be enabled as part of a service, limiting its use to the supported namespaces and requiring its use whenever supported. Link object is more of an application driven component and network service agnostic, allowing the network to decide on its use.

- Forwarding label can be considered as an enabler for faster packet processing at the ICN routers and optimized routing to a content source, whereas link object can be considered as a hint towards where to find the content. Since it is processed after FIB lookup on the content identifier fails, it typically leads to lower computational and bandwidth efficiency.

- As a link object can encode multiple routing hints, it can direct a request towards multiple identifier locations, giving an ICN router the option to choose any one of them based on the router's forwarding strategy. This selection is shared between consecutive hosts, but not enforced, which may lead to non-optimal forwarding paths. Forwarding label, on the other hand, is enforced consistently at consecutive hops within a domain whenever its use is supported.

## 4. Name Resolution System Considerations

To manage the AI to NI mapping, we need a name resolution system (NRS). In addition to exposing APIs to application to register its name to the NRS, it should also scale and work efficiently considering the scale of named resources that need to be published, resolved, removed, and updated at high frequency, for instance, corresponding to high-speed mobility scenarios.

The following are the design choices for the NRS:

- Hierarchical System: Here, AI to NI mapping is managed by the application providers, but similar to DNS, the service has to sync its name reachability information with high level name resolvers. NDNS is an example of such a system [NDNS]. This design is typically suitable in cases when resources are static, rather than for highly dynamic systems such as ICN, where replication and mobility will be the norm. Also, such system has to scale to resolve information objects in contrast to host resolution, which represents the current use.

- Integrated/Flat System: Here, resolution service is integrated within the ICN infrastructure, where the router contributes a part of its compute and storage resources to enable this service. This integration allows multiple ways of designing a generic name resolution service, similar to the designs for Global Name Resolution Service (GNRS) in MobilityFirst [GNS] [ASPC] [GNRS].

- o Distributed System: Compared to the flat system, this type of architecture preserves the contextual nature of DNS, by using the context in the name to identify a home controller, where respective AI to NI mapping can be resolved. At the same time, such a system removes the need for home controllers to sync up with high level resolvers. For instance, /company/content-id would be mapped with a resolver named /company/resolver-id.

## 5. Differences with respect to Existing IP-based Proposals

To address persistent identity, routing scalability, multihoming, and mobility limitations of the current IP, various incremental solutions have been proposed, among which identifier/locator split emerged as the key solution to address these challenges [RFC4984]. Here, we specifically focus on three of these solutions: (i) Host Identity Protocol (HIP) [HIP], (ii) Identifier-Locator Network Protocol (ILNP) [ILNP], and Locator/Identifier Seperation Protocol (LISP) [RFC6830]. HIP and ILNP achieve ID/locator separation and binding at the host level whereas LISP achieves that at the network level (i.e., at the network edge using service routers).

In HIP, public cryptographic keys are used as host identifiers, which provide the binding to higher layer protocols instead of IP addresses [RFC7401]. ILNP divides IP namespace into two distinct namespaces of identifiers and locators, each of which carrying distinct semantics with identifier representing the non-topological name for the host and locator representing the topologically bound name for the network [RFC6740]. LISP is a map-and-encap type protocol, which achieves id/locator separation by defining (i) endpoint identifiers, which are used for routing at the access network and which represent the IP address for the host, and (ii) routing locators, which are used for routing at the core and which represent the IP address for the egress routers.

These protocols fundamentally differ from ICN’s objective to define a new network layer, where name based routing, location independent caching, mobility, multihoming, and multi-path routing are the integral features. More specifically, this draft proposes to enable AI/NI binding as a network service to allow efficient routing of user requests depending on the application context.

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## Appendix A. Additional Stuff

This becomes an Appendix.

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