ICNRG
Internet-Draft
Intended status: Informational
Expires: July 19, 2018

A. Rahman
D. Trossen
InterDigital Inc.
D. Kutscher
R. Ravindran
Huawei

January 15, 2018

Deployment Considerations for Information-Centric Networking (ICN)

draft-rahman-icnrg-deployment-guidelines-05

Abstract

Information-Centric Networking (ICN) is now reaching technological maturity after many years of fundamental research and experimentation. This document provides a number of deployment considerations in the interest of helping the ICN community move forward to the next step of live deployments. First, the major deployment configurations for ICN are described including the key overlay and underlay approaches. Then proposed deployment migration paths are outlined to address major practical issues such as network and application migration. Next, selected ICN trial experiences are summarized. Finally, protocol areas that require further standardization are identified to facilitate future interoperable ICN deployments.

Status of This Memo

Copyright Notice

Table of Contents

1. Introduction

The ICNRG charter identifies deployment guidelines as an important topic area for the ICN community. Specifically, the charter states that defining concrete migration paths for ICN deployments which avoid forklift upgrades, and defining practical ICN interworking configurations with the existing Internet paradigm, are key topic areas that require further investigation [ICNRGCharter]. Also, it is well understood that results and conclusions from any mid to large-scale ICN experiments in the live Internet will also provide useful guidance for deployments.

However, so far outside of some preliminary investigations such as [I-D.paik-icn-deployment-considerations], there has not been much progress on this topic. This document attempts to fill some of these gaps by defining clear deployment configurations for ICN, and associated migration pathways for these configurations. Also, selected deployment trial experiences of ICN technology are summarized. Finally, recommendations are made for potential future IETF standardization of key protocol functionality that will facilitate interoperable ICN deployments going forward.

2. Terminology

This document assumes readers are, in general, familiar with the terms and concepts that are defined in [RFC7927] and [I-D.irtf-icnrg-terminology]. In addition, this document defines the following terminology:

Deployment - In the context of this document, deployment refers to the final stage of the process of setting up an ICN network that is (1) ready for useful work (e.g. transmission of end user video and text) in a live environment, and (2) integrated and interoperable with the Internet. We consider the Internet in its widest sense where it encompasses various access networks (e.g. WiFi, Mobile radio network), service edge networks (e.g. for edge computing), transport networks, Content Distribution Networks

(CDNs), core networks (e.g. Mobile core network), and back-end processing networks (e.g. Data Centres). However, through out the document we typically limit the discussion to edge networks, core networks and CDNs for simplicity.

Information-Centric Networking (ICN) - A data-centric network architecture where accessing data by name is the essential network primitive. See [I-D.irtf-icnrg-terminology] for further information.

Network Function Virtualization (NFV): A networking approach where network functions (e.g. firewalls, load balancers) are modularized as software logic that can run on general purpose hardware, and thus are specifically decoupled from the previous generation of proprietary and dedicated hardware. See [I-D.irtf-nfvrg-gaps-network-virtualization] for further information.

Software-Defined Networking (SDN) - A networking approach where the control and data plane for switches are separated, allowing for realizing capabilities such as traffic isolation and programmable forwarding actions. See [RFC7426] for further information.

3. Deployment Configurations

In this section, we present various deployment options for ICN. These are presented as "configurations" that allow for studying these options further. While this document will outline experiences with various of these configurations (in Section 5), we will not provide an in-depth technical or commercial evaluation for any of them - for this we refer to existing literature in this space such as [Tateson].

3.1. Clean-slate ICN

ICN has often been described as a "clean-slate" approach with the goal to renew or replace the complete IP infrastructure of the Internet (e.g., existing applications which are typically tied directly to the TCP/IP protocol stack, IP routers, etc.). As such, existing routing hardware as well as ancillary services are not taken for granted. For instance, a Clean-slate ICN deployment would see existing IP routers being replaced by ICN-specific forwarding and routing elements, such as NFD (Named Data Networking Forwarding Daemon) [NFD], CCN routers [Jacobson] or PURSUIT forwarding nodes [IEEE_Communications].

While such clean-slate replacement could be seen as exclusive for ICN deployments, some ICN approaches (e.g., [POINT]) also rely on the

deployment of general infrastructure upgrades, here SDN switches. Such SDN infrastructure upgrades, while being possibly utilized for a Clean-slate ICN deployment would not necessary be used exclusively for such deployments. Different proposals have been made for various ICN approaches to enable the operation over an SDN transport [Reed][CONET][C_FLOW].

3.2. ICN-as-an-Overlay

Similar to other significant changes to the Internet routing fabric, particularly the transition from IPv4 to IPv6 or the introduction of IP multicast, this deployment configuration foresees the creation of an ICN overlay. Note that this overlay approach is sometimes, informally, also referred to as a tunneling approach. The overlay approach can be implemented directly such as ICN-over-UDP as described in [CCNx_UDP]. Alternatively, the overlay can be accomplished via ICN-in-L2-in-IP as in [IEEE_Communications] which describes a recursive layering process. Another approach used in the Network of Information (NetInf) is to define a convergence layer to map NetInf semantics to HTTP [I-D.kutscher-icnrg-netinf-proto]. Finally, [Overlay_ICN] describes an incremental approach to deploying an ICN architecture based on segregating ICN user and control plane traffic which is particularly well-suited to being overlaid on SDN based networks.

Regardless of the flavor, however, the overlay approach results in islands of ICN deployments over existing IP-based infrastructure. Furthermore, these ICN islands are typically connected to each other via ICN/IP tunnels. In certain scenarios this requires interoperability between existing IP routing protocols (e.g. OSPF, RIP, ISIS) and ICN based ones. ICN-as-an-Overlay can be deployed over IP infrastructure in either edge or core networks. This overlay approach is thus very attractive for ICN experimentation and testing as it allows rapid and easy deployment of ICN over existing IP networks.

3.3. ICN-as-an-Underlay

Proposals such as [POINT] and [White] outline the deployment option of using an ICN underlay that would integrate with existing (external) IP-based networks by deploying application layer gateways at appropriate locations. The main reasons for such a configuration option is the introduction of ICN technology in given islands (e.g., inside a CDN or edge IoT network) to reap the benefits of native ICN in terms of underlying multicast delivery, mobility support, fast indirection due to location independence, in-network computing and possibly more. The underlay approach thus results in islands of native ICN deployments which are connected to the rest of the

Internet through protocol conversion gateways or proxies. Routing domains are strictly separated. Outside of the ICN island, normal IP routing protocols apply. Within the ICN island, ICN based routing schemes apply. The gateways transfer the semantic content of the messages (i.e., IP packet payload) between the two routing domains.

3.3.1. Edge Network

Native ICN networks may be located at the edge of the network which allows the possibility of introducing new network architectures and protocols, and in this context ICN is an attractive option for newer deployments such as IoT [I-D.irtf-icnrg-icniot]. The integration with the current IP protocol suite takes place at an application gateway/proxy at the edge network boundary, e.g., translating incoming CoAP request/response transactions [RFC7252] into ICN message exchanges or vice versa. Furthermore, ICN will allow enhancement of the role of gateways/proxies as ICN message security should be preserved through the protocol translation function of a gateway/proxy and thus offer a substantial gain.

The work in [VSER] positions ICN as an edge service gateway driven by a generalized ICN based service orchestration system with its own compute and network virtualization controllers to manage an ICN infrastructure. The platform also offers service discovery capabilities to enable user applications to discover appropriate ICN service gateways. To exemplify a use case scenario, the [VSER] platform shows the realization of a multi-party audio/video conferencing service over such a edge cloud deployment of ICN routers realized over commodity hardware platforms. This platform has also been extended to offer seamless mobility and mobility as a service [VSER-Mob] features.

3.3.2. Core Network

In this sub-option, a core network would utilize edge-based protocol mapping onto the native ICN underlay. For instance, [POINT] proposes to map HTTP transactions, or some other IP based transactions such as CoAP, directly onto an ICN-based message exchange. This mapping is realized at the network attachment point, such as realized in access points or customer premise equipment, which in turn provides a standard IP interface to existing user devices. Towards peering networks, such network attachment point turns into a modified border gateway/proxy, preserving the perception of an IP-based core network towards any peering network.

The work in [White] proposes a similar deployment configuration. Here, the target is the use of ICN for content distribution within CDN server farms, i.e., the protocol mapping is realized at the

ingress of the server farm where the HTTP-based retrieval request is served, while the response is delivered through a suitable egress node translation.

3.4. ICN-as-a-Slice

The objective of Network slicing [NGMN]is to multiplex a general pool of compute, storage and bandwidth resources among multiple services with exclusive SLA requirements on transport level QoS and security. From a 5G perspective, this also includes slicing the air interface spectrum resources among different applications. These services could include both connectivity services like LTE-as-a-service or OTT services like VoD or other IoT services through composition of a group of virtual and/or physical network functions. Such a framework can also be used to realize ICN slices with its own control, service and forwarding plane over which one or more end-user services can be delivered.

5G next generation architecture [fiveG-23501] provides the flexibility to deploy the ICN-as-a-Slice over either the edge (RAN) or Mobile core network, or the ICN-as-a-Slice may be deployed end-to-end. Further discussions on extending the architecture presented in [fiveG-23501] and the corresponding procedures in [fiveG-23502] to support ICN has been provided in [I-D.ravi-icnrg-5gc-icn]. Such a generalized network slicing framework should be able to offer service slices to be realized using both IP and ICN. Network slicing will rely heavily on network softwarization and programmability using SDN/NFV technologies for efficient utilization of available resources without compromising on the slice requirements. Coupled with the view of ICN functions as being "chained service functions" [RFC7665], an ICN deployment within such a slice could also be realized within the emerging orchestration plane that is targeted for adoption in future (e.g., 5G Mobile) network deployments. Finally, it should be noted that ICN is not creating the network slice, but instead that the slice is created to run an 5G-ICN instance [Ravindran].

At the level of the specific technologies involved, such as ONAP [ONAP] that can be used to orchestrate slices, the 5G-ICN slice requires compatibility for instance at the level of the forwarding/data plane depending on if it is realized as an overlay or using programmable data planes. With SDN emerging for new network deployments, some ICN approaches will need to integrate with SDN as a data plane forwarding function, as briefly discussed in Section 3.1. Further cross domain ICN slices can also be realized using frameworks such as [ONAP].

4. Deployment Migration Paths

After outlining the various ICN deployment configurations in Section 3, we now focus on the various migration paths that will have importance to the various stakeholders that are usually involved in the deployment of a technology at (ultimately) large scale. We can identify these stakeholders as:

- Application providers
- ISPs and service providers, both as core as well as access network providers, and also ICN network providers
- CDN providers (due to the strong relation of the ICN proposition to content delivery)
- End device manufacturers and users

Note that our presentation purely focuses on technological aspects of such migration. Economic or regulatory aspects, such as studied in [Tateson], [Techno_Economic] and [Internet_Pricing] are left out of our discussion.

4.1. Application and Service Migration

The internet is full of applications and services, utilizing the innovation capabilities of the many protocols defined over the packet level IP service. HTTP provides one convergence point for these services with many web development frameworks based on the semantics provided by the hypertext transfer protocol. In recent years, even services such as video delivery have been migrating from the traditional RTP-over-UDP delivery to the various HTTP-level streaming solutions, such as DASH [DASH] and others. Nonetheless, many non-HTTP services exist, all of which need consideration when migrating from the IP-based internet to an ICN-based one.

The underlay deployment configuration options presented in Section 3.3.2 and Section 3.3.1 aim at providing some level of backward compatibility to this existing ecosystem through a proxy based message flow mapping mechanism (e.g., mapping of existing HTTP/TCP/IP message flows to HTTP/TCP/IP/ICN message flows). A related approach of mapping TCP/IP to TCP/ICN message flows is described in [Moiseenko]

Alternatively, ICN as an overlay (Section 3.2), as well as ICN-as-a-Slice (Section 3.4), allow for the introduction of the full capabilities of ICN through new application/service interfaces as well as operations in the network. With that, these approaches of

deployment are likely to aim at introducing new application/services capitalizing on those ICN capabilities.

Finally, [I-D.suthar-icnrg-icn-lte-4g] outlines a dual-stack end user device approach that is applicable for all deployment configurations. Specifically, [I-D.suthar-icnrg-icn-lte-4g] introduces middleware layers (called the Transport Convergence Layer, TCL) in the device that will dynamically adapt existing applications to either an underlying ICN protocol stack or standard IP protocol stack. This involves end device signalling with the network to determine which protocol stack instance and associated middleware adaptation layers to utilize for a given application transaction.

4.2. Content Delivery Network Migration

A significant number of services and applications are devoted to content delivery in some form, either as video delivery services, social media platforms, and many others. Content delivery networks (CDNs) are deployed to assist these services through localizing the content requests and therefore reducing latency and possibly increase utilization of available bandwidth as well as reducing the load on origin servers. Similar to the previous sub-section, the underlay deployment configurations presented in Section 3.3.2 and Section 3.3.1 aim at providing a migration path for existing CDNs. This is also highlighted in the BIER WG use case document [I-D.ietf-bier-use-cases], specifically with potential benefits in terms of utilizing multicast in the delivery of content but also reducing load on origin as well as delegation server. We return to this benefit in the trial experiences in Section 5.

4.3. Edge Network Migration

Edge networks often see the deployment of novel network level technology, e.g., in the space of IoT. Such IoT deployments have for many years relied, and often still do, on proprietary protocols for reasons such as increased efficiency, lack of standardization incentives and others. Utilizing the underlay deployment configuration in Section 3.3.1, application gateways/proxies can integrate such edge deployments into IP-based services, e.g., utilizing CoAP [RFC7252] based machine-to-machine (M2M) platforms such as oneM2M [oneM2M] or others.

Another area of increased edge network innovation is that of Mobile (access) networks, particularly in the context of the 5G Mobile networks. With the proliferation of network softwarization (using technologies like service orchestration frameworks leveraging NFV and SDN concepts) access networks and other network segments, the ICN-as-a-Slice deployment configuration in Section 3.4 provides a suitable

migration path for integration non-IP-based edge networks into the overall system through virtue of realizing the relevant (ICN) protocols in an access network slice.

4.4. Core Network Migration

Migrating core networks (e.g., of the Internet or Mobile core network) requires not only significant infrastructure renewal but also the fulfillment of the significant performance requirements, particularly in terms of throughput. For those parts of the core network that would see a migration to an SDN-based optical transport the ICN-as-a-Slice deployment configuration in Section 3.4 could see the introduction of native ICN solutions within slices provided by the SDN-enabled transport network or as virtual network functions, allowing for isolating the ICN traffic while addressing the specific ICN performance benefits and constraints within such isolated slice. For ICN solutions that natively work on top of SDN, the underlay deployment configuration in Section 3.3.2 provides an additional migration path, preserving the IP-based services and applications at the edge of the network, while realizing the core network routing through an ICN solution (possibly itself realized in a slice of the SDN transport network).

5. Deployment Trial Experiences

In this section, we will outline trial experiences, often conducted within international collaborative project efforts. Our focus here is on the realization of the various deployment configurations in Section 3, and we therefore categorize the trial experiences according to these deployment configurations. While a large body of work exists at the simulation or emulation level, we specifically exclude these studies from our presentation to retain the focus on real life experiences.

5.1. ICN-as-an-Overlay

5.1.1. FP7 PURSUIT Efforts

Although the FP7 PURSUIT [IEEE_Communications] efforts were generally positioned as a Clean-slate ICN replacement of IP (Section 3.1), the project realized its experimental test bed as an L2 VPN-based overlay between several European, US as well as Asian sites, i.e., following the overlay deployment configuration presented in Section 3.2. Software-based forwarders were utilized for the ICN message exchange, while native ICN applications, e.g., for video transmissions, were showcased. At the height of the project efforts, about 70+ nodes were active in the (overlay) network with presentations given at several conferences as well as to the ICNRG.

5.1.2. FP7 SAIL Trial

The Network of Information (NetInf) is the approach to Information-Centric Networking developed by the European Union (EU) FP7 SAIL project (http://www.sail-project.eu/). NetInf provides both name-based forwarding with CCNx-like semantics and name resolution (for indirection and late-binding). The NetInf architecture supports different deployment options through its convergence layer abstraction. In its first prototypes and trials, NetInf was deployed mostly in an HTTP embedding and in a UDP overlay following the overlay deployment configuration in Section 3.2. Reference [SAIL_NetInf] describes several trials including a stadium environment large crowd scenario and a multi-site testbed, leveraging NetInf's Routing Hint approach for routing scalability.

5.1.3. NDN Testbed

The Named Data Networking (NDN) is one of the research projects funded by the National Science Foundation (NSF) of the USA as part of the Future Internet Architecture Program. The original NDN proposal was positioned as a Clean-slate ICN replacement of IP (Section 3.1). However, in several trials, NDN generally follows the overlay deployment configuration of Section 3.2 to connect institutions over the public Internet across several continents. The use cases covered in the trials include real-time video-conferencing, geo-locating, and interfacing to consumer applications. Typical trials involve up to 100 NDN enabled nodes (https://named-data.net/ndn-testbed/) [Jangam].

5.1.4. ICN2020 Efforts

ICN2020 is an ICN related research project funded by the EU and Japan as part of the H2020 research and innovation program and NICT (http://www.icn2020.org/). ICN2020 has a specific focus to advance ICN towards real-world deployments through innovative applications and global scale experimentation. Both NDN and CCN approaches are within the scope of the project.

ICN2020 was kicked off in July 2016 and at the end of the first year released a set of public technical reports [ICN2020]. The report titled "Deliverable D4.1: 1st yearly report on Testbed and Experiments (WP4)" contains a detailed description of the progress made in both local testbeds as well as federated testbeds. The plan for the federated testbed includes integrating the NDN testbed, the CUTEi testbed [RFC7945] [CUTEi] and the GEANT testbed (https://www.geant.org/) to create an overlay deployment configuration of Section 3.2 over the public Internet.

5.2. ICN-as-an-Underlay

5.2.1. H2020 POINT and RIFE Efforts

POINT and RIFE are two more ICN related research projects funded by the EU as part of the H2020 effort. The efforts in the H2020 POINT+RIFE projects follow the underlay deployment configuration in Section 3.3.2, although this is mixed with utilizing an overlay deployment to provide multi-national connectivity. However, underlay SDN-based deployments do exist at various project partner sites, e.g., at Essex University, without any overlaying being realized. Edge-based network attachment points (NAPs) provide the IP/HTTP-level protocol mapping onto ICN protocol exchanges, while the SDN underlay (or the VPN-based L2 underlay) is used as a transport network.

The multicast as well as service endpoint surrogate benefits in HTTP-based scenarios, such as for HTTP-level streaming video delivery, have been demonstrated in the deployed POINT test bed with 80+ nodes being utilized. Demonstrations of this capability have been given to the ICNRG in 2016, and public demonstrations were also provided at events such as Mobile World Congress in 2016 [MWC_Demo]. The trial has also been accepted by the ETSI MEC group as a proof-of-concept with a demonstration at the ETSI MEC World Congress in 2016.

While the afore-mentioned demonstrations all use the overlay deployment, H2020 also has performed ICN underlay trials. One such trial involved commercial end users located in the Primetel network in Cyprus with the use case centered on IPTV and HLS video dissemination. Another trial was performed in the community network of "guifi.net" in the Barcelona region, where the solution was deployed in 40 households, providing general Internet connectivity to the residents. Standard IPTV STBs as well as HLS video players were utilized in accordance with the aim of this deployment configuration, namely to provide application and service migration.

5.2.2. H2020 FLAME Efforts

The H2020 FLAME efforts concentrate on providing an experimental ground for the aforementioned POINT/RIFE solution in initially two city-scale locations, namely in Bristol and Barcelona. This trial followed the underlay deployment configuration in Section 3.3.2 as per POINT/RIFE approach. Experiments were conducted with the city/university joint venture Bristol-is-Open (BIO), to ensure the readiness of the city-scale SDN transport network for such experiments. Another trial was for the ETSI MEC PoC. This trial showcased operational benefits provided by the ICN underlay for the scenario of a location-based game. These benefits aim at reduced network utilization through improved video delivery performance

(multicast of all captured videos to the service surrogates deployed in the city at six locations) as well as reduced latency through the playout of the video originating from the local NAP instead of a remote server.

Ensuring the technology readiness and the early trialing of the ICN capabilities lays the ground for the goal of the H2020 FLAME efforts to conduct 23 large-scale experiments in the area of Future Media Internet (FMI) throughout 2018 and 2019. Standard media service functions as well as applications will ultimately utilize the ICN underlay in the delivery of their experience. The platform, which includes the ICN capabilities, will utilize concepts of SFC, integrated with NFV and SDN capabilities of the infrastructure. The ultimate goal of these platform efforts is the full integration of ICN into the overall media function platform for the provisioning of advanced (media-centric) internet services.

5.2.3. CableLabs Content Delivery System

The work in [White] proposes an underlay deployment configuration based on Section 3.3.2. The use case is ICN for content distribution within CDN server farms (which can be quite large and complex) to leverage ICN's superior in-network caching properties. This "island of ICN" based CDN is then used to service standard HTTP/IP-based content retrieval request coming from the general Internet. This approach acknowledges that whole scale replacement (see Section 3.1) of existing HTTP/IP end user applications and related Web infrastructure is a difficult proposition. [White] does not yet provide results but indicated that experiments will be forthcoming.

5.2.4. NDN IoT Trials

[Baccelli] summarizes the trial of an NDN system adapted specifically for a wireless IoT scenario. The trial was run with 60 nodes distributed over several multi-story buildings in a university campus environment. The NDN protocols were optimized to run directly over 6LoWPAN wireless link layers. The performance of the NDN based IoT system was then compared to an equivalent system running standard IP based IoT protocols. It was found that the NDN based IoT system was superior in several respects including in terms of energy consumption, and for RAM and ROM footprints [Baccelli] [Anastasiades].

5.3. Other Configurations

This section records deployment trial experiences from systems that do not directly correspond to one of the basic configurations defined in Section 3.

5.3.1. Hybrid ICN Trials

Hybrid ICN [Hybrid_ICN-1] [Hybrid_ICN-2] is an approach where the ICN names are mapped to IPv6 addresses, and other ICN information is carried as payload inside the IP packet. This allows standard (ICN-unaware) IP routers to forward packets based on IPv6 info, but enables ICN-aware routers to apply ICN semantics. A related open source effort was kicked off in 2017 (https://wiki.fd.io/view/Cicn). The intent of the trials are to show the routing performance efficiency of the Hybrid ICN router (called the Vector Packet Processor) over existing IP routers. Results have not yet been published but are expected in the near future.

5.4. Summary of Deployment Trials

In summary, there have been significant trials over the years with all the major ICN protocol flavors (e.g., CCN, NDN, POINT) using both the ICN-as-an-Overlay and ICN-as-an-Underlay deployment configurations. The major limitations of the trials include the fact that only a limited number of applications have been tested. However, the tested applications include both native ICN and existing IP based applications (e.g. video-conferencing and IPTV). Another limitation of the trials is that all of them involve less than 1000 users maximum.

The ICN-as-a-Slice configuration still has not be trialled primarily due to the fact that 5G standards are still in flux and not expected to be stable before the mid-2018 time frame. The Clean-slate ICN approach has obviously never been trialled as complete replacement of Internet infrastructure (e.g., existing applications, TCP/IP protocol stack, IP routers, etc.) is no longer considered a viable alternative. Finally, the Hybrid ICN approach offers an intersting alternative as it allows ICN semantics to be embedded in standard IPv6 packets and so the packets can be routed through either IP routers or Hybrid ICN routers. Detailed performance results are still pending for this alternative.

6. Deployment Issues Requiring Further Standardization

The ICN Research Challenges [RFC7927] describes key ICN principles and technical research topics. As the title suggests, [RFC7927] is research oriented without a specific focus on deployment or standardization issues. This section addresses this open area by identifying key protocol functionality that that may be relevant for further standardization effort in IETF. The focus is specifically on identifying protocols that will facilitate future interoperable ICN deployments correlating to the scenarios identified in the deployment

migration paths in Section 4. The identified list of potential protocol functionality is not exhaustive.

6.1. Protocols for Application and Service Migration

End user applications and services need a standardized approach to trigger ICN transactions. For example, in Internet and Web applications today, there are established socket APIs, communication paradigms such as REST, common libraries, and best practices. We see a need to study application requirements in an ICN environment further and, at the same time, develop new APIs and best practices that can take advantage of ICN communication characteristics.

6.2. Protocols for Content Delivery Network Migration

A key issue in CDNs is to quickly find a location of a copy of the object requested by an end user. In ICN, a Named Data Object (NDO) is typically defined by its name. There already exists [RFC6920] that is suitable for static naming of ICN data objects. Other ways of encoding and representing ICN names have been described in [I-D.irtf-icnrg-ccnxmessages] and [I-D.mosko-icnrg-ccnxurischeme]. Naming dynamically generated data requires different approaches (for example, hash digest based names would normally not work), and there is lack of established conventions and standards.

Another CDN issue for ICN is related to multicast distribution of content. Existing CDNs have started using multicast mechanisms for certain cases such as for broadcast streaming TV. However, as discussed in Section 5.2.1, certain ICN approaches provide substantial improvements over IP multicast, such as the implicit support for multicast retrieval of content in all ICN flavours.

Caching is an implicit feature in many ICN architectures that can improve performance and availability in several scenarios. The ICN in-network caching can augment managed CDN and improve its performance. The details of the interplay between ICN caching and managed CDN need further consideration.

6.3. Protocols for Edge and Core Network Migration

ICN provides the potential to redesign current edge and core network computing approaches. Leveraging ICN's inherent security and its ability to make name data and dynamic computation results available independent of location, can enable a secure, yet light-weight insertion of traffic into the network without relying on redirection of DNS requests. For this, proxies that translate from commonly used protocols in the general Internet to ICN message exchanges in the ICN domain could be used for the migration of application and services

within deployments at the network edge but also in core networks. This is similar to existing approaches for IoT scenarios where a proxy translates CoAP request/responses to other message formats. For example, [RFC8075] specifies proxy mapping between CoAP and HTTP protocols. However, as mentioned previously, ICN will allow us to evolve the role of gateways/proxies as ICN message security should be preserved through the protocol translation function of a thus offer a substantial gain.

Interaction and interoperability between existing IP routing protocols (e.g., OSPF, RIP, ISIS) and ICN routing approaches(e.g., NFD, CCN routers) are expected especially in the overlay approach. Another important topic is integration of ICN into networks that support virtualized infrastructure in the form of NFV/SDN and most likely utilizing Service Function Chaining (SFC) as a key protocol. Further work is required to validate this idea and document best practices.

Operations and Maintenance (OAM) is a crucial area that has not yet been fully addressed by the ICN research community, but which is obviously critical for future deployments of ICN. Potential areas that need investigation include whether the YANG data modelling approach and associated NETCONF/RESTCONF protocols need any specific updates for ICN support. Another open area is how to measure and benchmark performance of ICN networks comparable to the sophisticated techniques that exist for standard IP networks, virtualized networks and data centers. It should be noted that some initial progress has been made in the area of ICN network path traceroute facility with approaches such as CONTRACE [I-D.asaeda-icnrg-contrace] [Contrace].

6.4. Summary of ICN Protocol Gaps and Potential Protocol Efforts

Without claiming completeness, Table 1 maps the open the open ICN issues identified in this document to potential protocol efforts that could address some aspects of the gap.

ICN Gap	Potential Protocol Effort
1-Support of REST APIs	HTTP/CoAP support of ICN semantics
2-Naming	Dynamic naming of ICN data objects
3-Routing	Interactions between IP and ICN routing protocols
4-Multicast distribution	Multicast enhancements for ICN
5-In-network caching	ICN Cache placement and sharing
6-NFV/SDN support	Integration of ICN with NFV/SDN and including possible impacts to SFC
7-ICN mapping	Mapping of HTTP and other protocols onto ICN message exchanges (and vice-versa) while preserving ICN message security
8-OAM support	YANG models, NETCONF/RESTCONF protocols, and network performance measurements

Table 1: Mapping of ICN Gaps to Potential Protocol Efforts

7. Conclusion

This document provides high level deployment considerations for the ICN community. Specifically, the major configurations of possible ICN deployments are identified as (1) Clean-slate ICN replacement of existing Internet infrastructure; (2) ICN-as-an-Overlay; (3) ICN-as-an-Underlay; and (4) ICN-as-a-Slice. Existing ICN trial systems primarily fall under either the ICN-as-an-Overlay or ICN-as-an-Underlay configuration.

In terms of deployment migration paths, ICN-as-an-Underlay offers a clear migration path for CDN, edge and core networks to go to an ICN paradigm (e.g., for an IoT deployment). ICN-as-an-Overlay is probably the easiest configuration to deploy as it leaves the underlying IP infrastructure essentially untouched. However its applicability for general deployment must be considered on a case by case basis (e.g., based on if it can run all required applications or other similar criteria). ICN-as-a-Slice is an attractive deployment

option for future 5G systems (i.e., for 5G radio and core networks) which will naturally support network slicing, but this still has to be validated through actual trial experiences.

For the crucial issue of existing application and service migration to ICN, various mapping schemes are possible to mitigate impacts. For example, HTTP/TCP/IP flows may be mapped to/from ICN message flows at proxies in the ICN-as-an-Underlay configurations leaving the massive number of existing end point applications/services untouched or minimally impacted. Also dual stack end user devices that include middleware to allow applications to communicate in both ICN mode and standard IP mode are an attractive proposition for gradual and geographically discontinuous introduction for all deployment configurations.

There has been significant trial experience with all the major ICN protocol flavors (e.g., CCN, NDN, POINT). However, only a limited number of applications have been tested so far, and the maximum number of users in any given trial has been less than 1000 users. It is recommended that future ICN deployments scale their users gradually and closely monitor network performance as they go above 1000 users.

Finally, this document describes a set of technical features in ICN that warrant potential future IETF specification work. This will aid initial and incremental deployments to proceed in an interoperable manner. The fundamental details of the potential protocol specification effort, however, are best left for future study by the appropriate IETF WGs and/or BoFs.

8. IANA Considerations

This document requests no IANA actions.

9. Security Considerations

ICN was purposefully designed from the start to have certain intrinsic security properties. The most well known of which are authentication of delivered content and (optional) encryption of the content. [RFC7945] has an extensive discussion of various aspects of ICN security including many which are relevant to deployments. Specifically, [RFC7945] points out that ICN access control, privacy, security of in-network caches, and protection against various network attacks (e.g. DoS) have not yet been fully developed due to the lack of real deployments. [RFC7945] also points out relevant advances occurring in the ICN research community that hold promise to address each of the identified security gaps. Lastly, [RFC7945] points out that as secure communications in the existing Internet (e.g. HTTPS)

becomes the norm, that major gaps in ICN security will inevitably slow down the adoption of ICN.

In addition to the security findings of [RFC7945], this document has highlighted that all anticipated ICN deployment configurations will involve co-existence with existing Internet infrastructure and applications. Thus even the basic authentication and encryption properties of ICN content will need to account for interworking with non-ICN content to preserve end-to-end security. For example, in the edge network underlay deployment configuration described in Section 3.3.1, the gateway/proxy that translates HTTP or CoAP request/responses into ICN message exchanges will need to support a model to preserve end-to-end security.

10. Acknowledgments

The authors want to thank Alex Afanasyev, Mayutan Arumaithurai, Hitoshi Asaeda, Giovanna Carofiglio, Xavier de Foy, Hannu Flinck, Anil Jangam, Luca Muscariello, Dave Oran, Thomas Schmidt, Jan Seedorf, Eve Schooler, Samar Shailendra, Milan Stolic, Prakash Suthar, Atsushi Tagami, and Lixia Zhang for their very useful reviews, comments and input to the document.

11. Informative References

[Anastasiades]
Anastasiades, C., "Information-centric communication in mobile and wireless networks", PhD Dissertation, 2016, <http://boris.unibe.ch/83683/1/16anastasiades_c.pdf>.

[Baccelli]
Baccelli, E. and et al., "Information Centric Networking in the IoT: Experiments with NDN in the Wild", ACM 20164, Paris, France, 2014, <http://conferences2.sigcomm.org/acm-icn/2014/papers/p77.pdf>.

[C_FLOW] Suh, J. and et al., "C_FLOW: Content-Oriented Networking over OpenFlow", Open Networking Summit, April, 2012, <http://opennetsummit.org/archives/apr12/site/pdf/snu.pdf>.

[CCNx_UDP]
PARC, "CCNx Over UDP", 2015, <https://www.ietf.org/proceedings/interim-2015-icnrg-04/slides/slides-interim-2015-icnrg-4-5.pdf>.

[CONET]   Veltri, L. and et al., "CONET Project: Supporting Information-Centric Functionality in Software Defined Networks", Workshop on Software Defined Networks, , 2012, <http://netgroup.uniroma2.it/Stefano_Salsano/papers/salsano-icc12-wshop-sdn.pdf>.

[Contrace]
Asaeda, H. and et al., "Contrace: A Tool for Measuring and Tracing Content-Centric Networks", IEEE Communications Magazine, Vol.53, No.3 , 2015.

[CUTEi]   Asaeda, H. and N. Choi, "Container-Based Unified Testbed for Information Centric Networking", IEEE Network, Vol.28, No.6 , 2014.

[DASH]   DASH, "DASH Industry Forum", 2017, <http://dashif.org/>.

[fiveG-23501]
3gpp-23.501, "Technical Specification Group Services and System Aspects; System Architecture for the 5G System (Rel.15)", 3GPP , 2017.

[fiveG-23502]
3gpp-23.502, "Technical Specification Group Services and System Aspects; Procedures for the 5G System (Rel.15)", 3GPP , 2017.

[Hybrid_ICN-1]
Cisco, "Hybrid ICN: Cisco Announces Important Steps toward Adoption of Information-Centric Networking", 2017, <http://blogs.cisco.com/sp/cisco-announces-important-steps-toward-adoption-of-information-centric-networking>.

[Hybrid_ICN-2]
Cisco, "Mobile Video Delivery with Hybrid ICN: IP-Integrated ICN Solution for 5G", 2017, <https://www.cisco.com/c/dam/en/us/solutions/collateral/service-provider/ultra-services-platform/mwc17-hicn-video-wp.pdf>.

[I-D.asaeda-icnrg-contrace]
Asaeda, H., Shao, X., and T. Turletti, "Contrace: Traceroute Facility for Content-Centric Network", draft-asaeda-icnrg-contrace-04 (work in progress), October 2017.

[I-D.ietf-bier-use-cases]
Kumar, N., Asati, R., Chen, M., Xu, X., Dolganow, A., Przygienda, T., Gulko, A., Robinson, D., Arya, V., and C. Bestler, "BIER Use Cases", draft-ietf-bier-use-cases-05 (work in progress), July 2017.

[I-D.irtf-icnrg-ccnxmessages]
Mosko, M., Solis, I., and C. Wood, "CCNx Messages in TLV Format", draft-irtf-icnrg-ccnxmessages-06 (work in progress), October 2017.

[I-D.irtf-icnrg-icniot]
Ravindran, R., Zhang, Y., Grieco, L., Lindgren, A., Raychadhuri, D., Baccelli, E., Burke, J., Wang, G., Ahlgren, B., and O. Schelen, "Design Considerations for Applying ICN to IoT", draft-irtf-icnrg-icniot-00 (work in progress), January 2018.

[I-D.irtf-icnrg-terminology]
Wissingh, B., Wood, C., Afanasyev, A., Zhang, L., Oran, D., and C. Tschudin, "Information-Centric Networking (ICN): CCN and NDN Terminology", draft-irtf-icnrg-terminology-00 (work in progress), December 2017.

[I-D.irtf-nfvrg-gaps-network-virtualization]
Bernardos, C., Rahman, A., Zuniga, J., Contreras, L., Aranda, P., and P. Lynch, "Network Virtualization Research Challenges", draft-irtf-nfvrg-gaps-network-virtualization-08 (work in progress), November 2017.

[I-D.kutscher-icnrg-netinf-proto]
Kutscher, D., Farrell, S., and E. Davies, "The NetInf Protocol", draft-kutscher-icnrg-netinf-proto-01 (work in progress), February 2013.

[I-D.mosko-icnrg-ccnxurischeme]
marc.mosko@parc.com, m. and c. cwood@parc.com, "The CCNx URI Scheme", draft-mosko-icnrg-ccnxurischeme-01 (work in progress), April 2016.

[I-D.paik-icn-deployment-considerations]
Paik, E., Yun, W., Kwon, T., and h. hgchoi@mmlab.snu.ac.kr, "Deployment Considerations for Information-Centric Networking", draft-paik-icn-deployment-considerations-00 (work in progress), July 2013.

[I-D.ravi-icnrg-5gc-icn]
Ravindran, R., suthar, P., and G. Wang, "Enabling ICN in 3GPP's 5G NextGen Core Architecture", draft-ravi-icnrg-5gc-icn-00 (work in progress), October 2017.

[I-D.suthar-icnrg-icn-lte-4g]
suthar, P., Stolic, M., Jangam, A., and D. Trossen, "Native Deployment of ICN in LTE, 4G Mobile Networks", draft-suthar-icnrg-icn-lte-4g-04 (work in progress), November 2017.

[ICN2020] ICN2020, "ICN2020 Deliverables", 2017, <http://www.icn2020.org/dissemination/deliverables-public/>.

[ICNRGCharter]
NDN, "Information-Centric Networking Research Group Charter", 2013, <https://datatracker.ietf.org/doc/charter-irtf-icnrg/>.

[IEEE_Communications]
Trossen, D. and G. Parisis, "Designing and Realizing an Information-Centric Internet", Information-Centric Networking, IEEE Communications Magazine Special Issue, 2012.

[Internet_Pricing]
Trossen, D. and G. KBiczok, "Not Paying the Truck Driver: Differentiated Pricing for the Future Internet", ReArch Workshop in conjunction with ACM Context, December, 2010.

[Jacobson]
Jacobson, V. and et al., "Networking Named Content", Proceedings of ACM Context, , 2009.

[Jangam] Jangam, A. and et al., "Porting and Simulation of Named-data Link State Routing Protocol into ndnSIM", ACM DIVANet'17, Miami Beach, USA, 2017, <http://symposium.nsercdiva.com/2017/program.html>.

[Moiseenko]
Moiseenko, I. and D. Oran, "TCP/ICN : Carrying TCP over Content Centric and Named Data Networks", 2016, <http://conferences2.sigcomm.org/acm-icn/2016/proceedings/p112-moiseenko.pdf>.

[MWC_Demo]
InterDigital, "InterDigital Demo at Mobile World Congress (MWC)", 2016, <http://www.interdigital.com/download/56d5c71bd616f892ba001861>.

[NFD] NDN, "NFD - Named Data Networking Forwarding Daemon", 2017, <https://named-data.net/doc/NFD/current/>.

[NGMN] NGMN, "NGMN 5g Initiative White Paper", 2015, <https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf>.

[ONAP] ONAP, "Open Network Automation Platform", 2017, <https://www.onap.org/>.

[oneM2M] OneM2M, "oneM2M Service Layer Standards for M2M and IoT", 2017, <http://www.onem2m.org/>.

[Overlay_ICN]
Shailendra, S. and et al., "A Novel Overlay Architecture for Information Centric Networking", 2016, <https://www.researchgate.net/publication/282779666_A_novel_overlay_architecture_for_Information_Centric_Networking>.

[POINT] Trossen, D. and et al., "POINT: IP Over ICN - The Better IP?", European Conference on Networks and Communications (EuCNC), , 2015.

[Ravindran]
Ravindran, R., Chakraborti, A., Amin, S., Azgin, A., and G. Wang, "5G-ICN : Delivering ICN Services over 5G using Network Slicing", IEEE Communication Magazine, May, 2016, <https://arxiv.org/abs/1610.01182>.

[Reed] Reed, M. and et al., "Stateless Multicast Switching in Software Defined Networks", ICC 2016, Kuala Lumpur, Malaysia, 2016.

[RFC6920] Farrell, S., Kutscher, D., Dannewitz, C., Ohlman, B., Keranen, A., and P. Hallam-Baker, "Naming Things with Hashes", RFC 6920, DOI 10.17487/RFC6920, April 2013, <https://www.rfc-editor.org/info/rfc6920>.

[RFC7252] Shelby, Z., Hartke, K., and C. Bormann, "The Constrained Application Protocol (CoAP)", RFC 7252, DOI 10.17487/RFC7252, June 2014, <https://www.rfc-editor.org/info/rfc7252>.

[RFC7426] Haleplidis, E., Ed., Pentikousis, K., Ed., Denazis, S., Hadi Salim, J., Meyer, D., and O. Koufopavlou, "Software-Defined Networking (SDN): Layers and Architecture Terminology", RFC 7426, DOI 10.17487/RFC7426, January 2015, <https://www.rfc-editor.org/info/rfc7426>.

[RFC7665] Halpern, J., Ed. and C. Pignataro, Ed., "Service Function Chaining (SFC) Architecture", RFC 7665, DOI 10.17487/RFC7665, October 2015, <https://www.rfc-editor.org/info/rfc7665>.

[RFC7927] Kutscher, D., Ed., Eum, S., Pentikousis, K., Psaras, I., Corujo, D., Saucez, D., Schmidt, T., and M. Waehlisch, "Information-Centric Networking (ICN) Research Challenges", RFC 7927, DOI 10.17487/RFC7927, July 2016, <https://www.rfc-editor.org/info/rfc7927>.

[RFC7945] Pentikousis, K., Ed., Ohlman, B., Davies, E., Spirou, S., and G. Boggia, "Information-Centric Networking: Evaluation and Security Considerations", RFC 7945, DOI 10.17487/RFC7945, September 2016, <https://www.rfc-editor.org/info/rfc7945>.

[RFC8075] Castellani, A., Loreto, S., Rahman, A., Fossati, T., and E. Dijk, "Guidelines for Mapping Implementations: HTTP to the Constrained Application Protocol (CoAP)", RFC 8075, DOI 10.17487/RFC8075, February 2017, <https://www.rfc-editor.org/info/rfc8075>.

[SAIL_NetInf] FP7, "SAIL Prototyping and Evaluation", 2013, <http://www.sail-project.eu/wp-content/uploads/2013/05/SAIL_DB4_v1.1_Final_Public.pdf>.

[Tateson] Tateson, J. and et al., "Final Evaluation Report on Deployment Incentives and Business Models", 2010, <http://www.psirp.org/files/Deliverables/FP7-INFSO-ICT-216173-PSIRP-D4.6_FinalReportOnDeplIncBusinessModels.pdf>.

[Techno_Economic] Trossen, D. and A. Kostopolous, "Techno-Economics Aspects of Information-Centric Networking", Journal for Information Policy, Volume 2, 2012.

[VSER] Ravindran, R., Liu, X., Chakraborti, A., Zhang, X., and G. Wang, "Towards software defined ICN based edge-cloud services", CloudNetworking(CloudNet), IEEE Internation Conference on, IEEE Internation Conference on CloudNetworking(CloudNet), 2013.

[VSER-Mob] Azgin, A., Ravindran, R., Chakraborti, A., and G. Wang, "Seamless Mobility as a Service in Information-centric Networks", ACM ICN Sigcomm, IC5G Workshop, 2016.

[White] White, G. and G. Rutz, "Content Delivery with Content Centric Networking, CableLabs White Paper", 2010, <http://www.cablelabs.com/wp-content/uploads/2016/02/Content-Delivery-with-Content-Centric-Networking-Feb-2016.pdf>.

Appendix A. Change Log

[Note to RFC Editor: Please remove this section before publication.]

Changes from rev-04 to rev-05:

- o Added this Change Log in Appendix A.
- o Removed references to Hybrid ICN from section 3.2 (ICN-as-an-Overlay definition). Instead, consolidated all Hybrid ICN info in the Deployment Trial Experiences under a new subsection 5.3 (Other Configurations).
- o Updated ICN2020 description in Section 5.1.4 with text received from Mayutan Arumaithurai and Hitoshi Asaeda.
- o Clarified in ICN-as-a-Slice description (section 3.4) that it may be deployed on either the Edge (RAN) or Core Network, or the ICN-as-a-Slice may be deployed end-to-end through the entire Mobile network.
- o Added several new references in various sections.
- o Various minor editorial updates.

Authors' Addresses

Akbar Rahman
InterDigital Inc.
1000 Sherbrooke Street West, 10th floor
Montreal H3A 3G4
Canada

Email: Akbar.Rahman@InterDigital.com
URI: http://www.InterDigital.com/

Dirk Trossen
InterDigital Inc.
64 Great Eastern Street, 1st Floor
London EC2A 3QR
United Kingdom

Email: Dirk.Trossen@InterDigital.com
URI: http://www.InterDigital.com/

Dirk Kutscher
Huawei German Research Center
Riesstrasse 25
Munich 80992
Germany

Email: ietf@dkutscher.net
URI: http://www.Huawei.com/

Ravi Ravindran
Huawei Research Center
2330 Central Expressway
Santa Clara 95050
USA

Email: ravi.ravindran@huawei.com
URI: http://www.Huawei.com/