



# Interworking Between IP and ICN with New IP

Lijun Dong<sup>(✉)</sup> and Richard Li

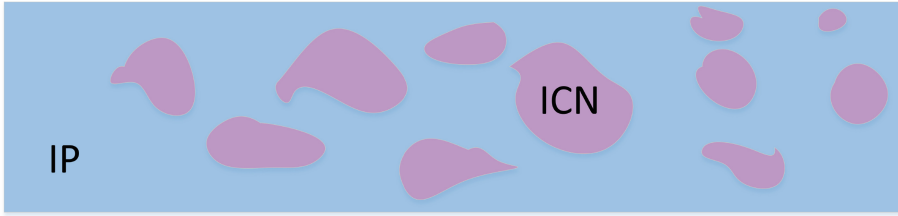
Futurewei Technologies Inc., 2220 Central Expressway, Santa Clara, CA 95050, USA  
{lijun.dong,richard.li}@futurewei.com

**Abstract.** Although Information Centric Networking (ICN) has many advantages over IP protocols regarding content requests, which is the majority traffic in the Internet, it is predicted that ICN will be likely to co-exist and be surrounded by an IP ocean. The paper proposes to leverage the newly proposed New IP framework to provide interworking solutions between ICN and IP. The proposed scheme addresses the limitations of the existing point solutions, which does not require new addressing design, because New IP offers flexible and asymmetric addressing for source and destination. The proposed scheme can also accommodate the performance guaranteed service regarding for example end-to-end latency for content requests, by considering the requesters' context, content distribution and network conditions etc.

**Keywords:** Contract · Metadata · Qualitative Communication · Information Centric Networking · ICN · Named Data Network · NDN · ICN Island · IP Sea · Interconnection

## 1 Introduction

The Information Centric Networking paradigm (ICN) changes the traditional host-centric communication in the current IP based Internet to the information-centric communication. In the traditional host-centric communication, two end-points need to be aware of each other's IP address before the communication could be initiated. Contrarily in ICN, which has been proposed to better serve content request and retrieval, end-points do not need to know the content location in the network, but simply let the ICN routers forward the requests to the nearest location based on the requested content names or identifiers. ICN has been proven to provide many advantages over the IP protocols for the optimization of content distribution, such as latency reduction and network load reduction due to in-network caching, better mobility support, etc. The benefits of ICN can only be shown fully under the circumstance that the current IP-based Internet is going to be completely replaced by ICN, which is undoubtedly challenging or even infeasible. We can foresee a more realistic deployment of ICN [1] is for it to grow, coexist and interconnect with IP-based Internet, in which ICN islands are surrounded by an IP ocean.



**Fig. 1.** ICN islands in IP ocean

There are various proposals for ICN. One of the such outstanding efforts is Named Data Networking (NDN) [4]. NDN uses names to identify every piece of data content instead of IP addresses for hardware devices attached to IP network. The NDN architecture and primitives are used in this paper for the illustration of the proposals.

To avoid ICN islands being totally isolated, how to communicate between the NDN island and IP ocean is an inevitable issue that need to be addressed. User Datagram Protocol (UDP) tunneling has been considered to be a common solution [2], in which ICN request or data messages are manually encapsulated in UDP packets, traverse the IP ocean and are unpacked at the receiving ICN gateway node. Automatic configuration of UDP tunnels between ICN domains was proposed in [3] through Software Defined Networking (SDN).

A different approach was presented by Cisco called Hybrid ICN (hICN) [5], where ICN packets are structured to be fully compatible with the IPv6 packet format. The name prefix is encoded as an IPv6 128 bits word and carried in IPv6 header fields. For a content request, the name prefix is stored in the DST address field to take advantage of IP routing/forwarding. For a content reply, the name prefix is stored in the SRC address field, which is not used for IP routing/forwarding. Name suffix is encoded in transport headers fields such as Transport Control Protocol (TCP). Thus a content Name is hierarchical concatenation of name prefix and suffix. All ICN features such as name-based forwarding and selective in-network caching are preserved. ICN specific features such as interest aggregation, in-network caching are only performed at those special routers deployed with a hICN forwarding module.

Although there are point solutions [6] to provide the transmission of ICN packets over IP networks, they have limitations as followings:

- They require the name prefixes to be carried in the IPv6 field (at most 6 bytes), and the name suffixes are carried in the underlying transport protocol field, which restricts the expressiveness and flexibility of name representation. The length of the content name is small for the real life scenarios.
- They can not support any performance guaranteed services, for example context awareness, user orientation, high precision, QoS/QoE assurance for the content distribution in emerging applications, which have already been proposed to be supported in NDN protocols [7] and [8]. In order for those context

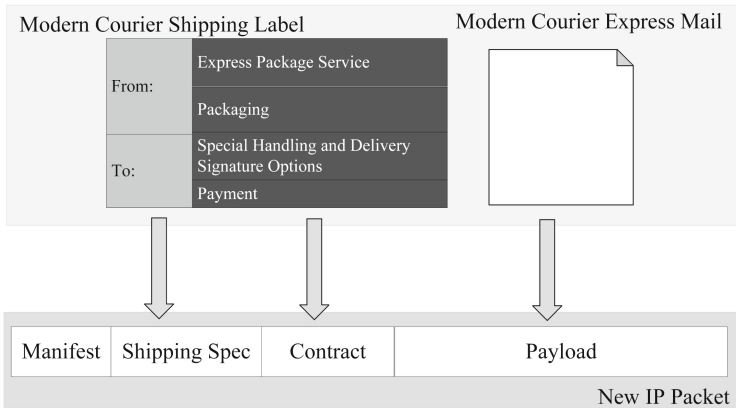
and semantics to be understood by the network as well, the interconnection mechanism needs to be redesigned/reconsidered between IP and ICN domains.

## 2 Overview of New IP

New IP [9] has been designed to be a unified framework and data plane technology that overcomes the issues of many overlay-based approaches or middle-box insertion, such as lack of flexibility in the data plane, limited scalability, complicated deployment and maintenance with many provisioning touch points.

If the data transport in the current Internet resembles to the delivery logistics in traditional postal mail services, New IP is designed to resemble the modern courier with many value-added services as shown in Fig. 2, for example that are customizable according to end points’ preferences and contexts, that are guaranteeable regarding end-to-end latency, packet loss ratio, and throughput etc., that provide trackability to end-points.

Evolved from the traditional IP packet with only header and user payload, New IP’s modern courier like datagram is harnessed with “Contract”. The manifest component keeps logistics and book-keeping information about the packet. The Shipping specification component provides the maximum flexibility for the format and size that could be adopted by source and destination addresses. The shipping specification allows the source and destination’s formats to be different, i.e., asymmetric addressing [10]. With this capability, traffic from an ICN island can be forwarded to the IP ocean and vice versa, without any need for an end-to-end UDP tunnelling.



**Fig. 2.** New Internet Protocol (New IP) Evolution

The New IP Contract provides a piece of machinery to enable new types of modern courier like advanced network services at the finest packet-level granularity. The structure of the contract is defined in a Chomsky style as shown in

Fig. 3. A New IP packet could have multiple contract clauses, each is composed of Event/Condition, Action and Metadata. The Event/Condition contains the triggers for a network node to take the Action specified in the contract. The Metadata includes the semantics, contexts that are associated with the parties involved in the Contract, as well as the packet payload itself.

---

```

<Contract> := <Contract clause>
           | <Contract clause> AND <Contract>

<Contract clause> := <Contract ECA>
                  | <Contract ECA> OR <Contract clause>

<Contract ECA> := <Event, Condition, Action>
                | <Metadata>
                | <Event, Condition, Action> <Metadata>
                | <Action>
                | <Action><Metadata>

```

---

**Fig. 3.** New IP Contract

The New IP payload can be a traditional payload as a sequence of bits/bytes, or a qualitative payload that facilitates Qualitative Communication [11] in the network when certain events happen or conditions are met.

Qualitative payload has finer granularity than the traditional payload, which means that different portions in the qualitative payload could be self-contained and can be processed by the network independently regarding dropping, enriching when network conditions change. Each portion of the qualitative payload might be associated with its own semantics, e.g., significance level, relationship to other portions. The use cases and benefits provided by such design are illustrated in many of our works [12–15] and [16].

### 3 Named Data Networking (NDN)

In this paper, we use NDN as an example of ICN architectures to show the interworking between IP and ICN enabled by New IP. NDN is a clean-slate network architecture for future Internet, which no longer concentrates on “where” the information is located, but “what” the information (content) is needed. NDN uses names to identify every piece of contents instead of IP addresses for hardware devices attached to IP network. An NDN name is hierarchically structured and composed of explicitly delimited components. Content request is enabled by interest and data packets in NDN. The interest packet shows the content request interest from the end user, which contains the content name being requested, and some selectors including order preference, publisher filer, scope and etc. The data packet includes the content name, security related information (i.e., signature, publisher ID, key locator, stale time, etc.), and the retrieved content data.

A NDN router maintains three data structures: the Forwarding Information Base (FIB) that associates the content names to the forwarding face(s) towards the producer(s), the Pending Interest Table (PIT) that records the incoming faces where the interests came from and have not replied by producer, the Content Store (CS) that caches content from a producer when it is forwarded to the users.

## 4 ICN Island Interconnection

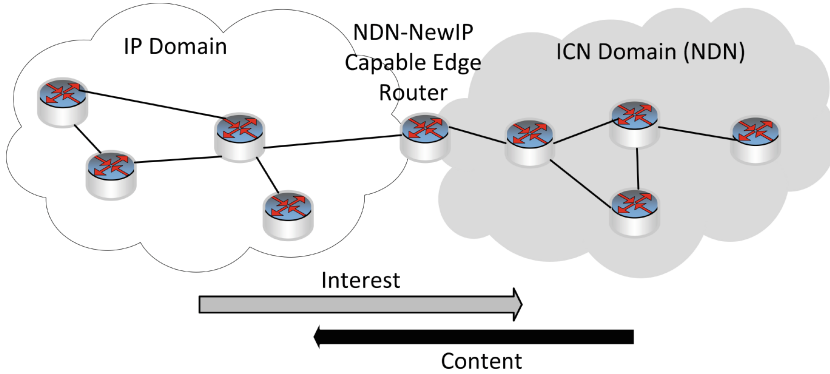
In this section, we present the inter-working solutions to connect the ICN islands in IP sea, which are enabled and provided by the New IP framework. We discuss three interconnection scenarios: (1) Requester in IP domain requesting content in NDN Domain ( $IP \rightarrow NDN$ ); (2) Requester in NDN domain requesting Content in IP domain ( $NDN \rightarrow IP$ ); (3) Requester in one NDN domain requesting content in another NDN Domain with IP domain in the middle ( $NDN \rightarrow IP \rightarrow NDN$ ). Although there is another possible scenario, in which requester is located in one IP domain and content provider resides in another IP domain with one NDN domain in the middle ( $IP \rightarrow NDN \rightarrow IP$ ), there is IP tunnel built between the two edge routers, thus the IP request packet can be simply routed through the NDN domain by the IP tunnel.

### 4.1 $IP \rightarrow NDN$

In this scenario as shown in Fig. 4, the client resides in an IP domain, in which the IP routers are upgraded with New IP capabilities. The content provider resides in the NDN domain. Each NDN router in the NDN domain including the NDN-NewIP capable router maintains a FIB for all name prefixes stored in the NDN domain. In the IP domain, clients may not know the address of content host in the NDN domain. New IP can integrate the content discovery and forwarding in one New IP packet. The client sends a New IP packet that contains the following information:

- Contract ECA, which is optional. The ECA that contained in each packet’s contract header could be removed if the New IP router has been provisioned with the ECA:
  - Add the domain ID and domain type, and forward the New IP packet to the corresponding NDN-NewIP capable boarder router if the current router has such knowledge.
  - Drop the packet if the current router finds the domain (denoted in domain ID) does not host the content.
- Metadata could include:
  - Packet type: interest (request content hosted in ICN domain);
  - Content name (prefix + suffix);
  - QoS criteria for content request (e.g., latency);
  - Client’s context for content producer selection;

- Conditions on returned content properties (e.g., size, resolution, format, etc.);
- Selector: order preference, publisher filter, scope and etc. (defined in the native NDN interest message);
- Next-hop Domain ID: the identifier of the next-hop domain towards the selected content provider.
- Next-hop Domain type: the type of the next-hop domain, in the scope of this paper, which could be NDN, or IP.



**Fig. 4.** Content request scenario: IP  $\rightarrow$  NDN

It is assumed that the routers in the IP domain are upgraded to be New IP capable. For the content request initiated in the IP domain, usually the client does not have the idea where the content is located, but only the content name. Thus when the packet reaches the edge router that the client connects to, the edge router will firstly find out whether it has knowledge of the content provider. If it somehow learns about this information from the previous content requests, it will configure the destination IP address to be the content provider's IP address. Otherwise the destination address is set to be the NDN-NewIP capable router's IP address. If there are multiple NDN domains that the IP domain connects to, then the packet will be replicated, with the number of duplication equal to the number of NDN domains. When other router in the IP domain receives a New IP packet indicating it is an interest packet, the router firstly checks whether the destination IP address is configured in the packet. If yes, it simply forwards the packet to the destination IP address. If the destination is configured as the IP address of a NDN-NewIP capable router, on the other hand, if the current IP router has the knowledge of the content provider, then the destination address is revised to the IP address of the content provider. If eventually the packet (with metadata indicating that it has packet type as interest) reaches the NDN-NewIP capable router, the NDN-NewIP capable router converts the packet to an interest message, records the New IP packet for returned content matching and

forwards the interest to the NDN domain. The Metadata in the New IP packet with interest type contains not only all necessary information for configuration of the standard interest message defined in NDN, but also accommodates the performance guaranteed service for content request proposed in [7] and [8]. The requested content will be returned from the NDN domain and reach the NDN-NewIP capable router, which in turn reconstructs the data packet by changing the destination address to be the content requester, which has been recorded in the pending interest list. The above procedures that are taken by routers in the IP domain are illustrated in Fig. 5.

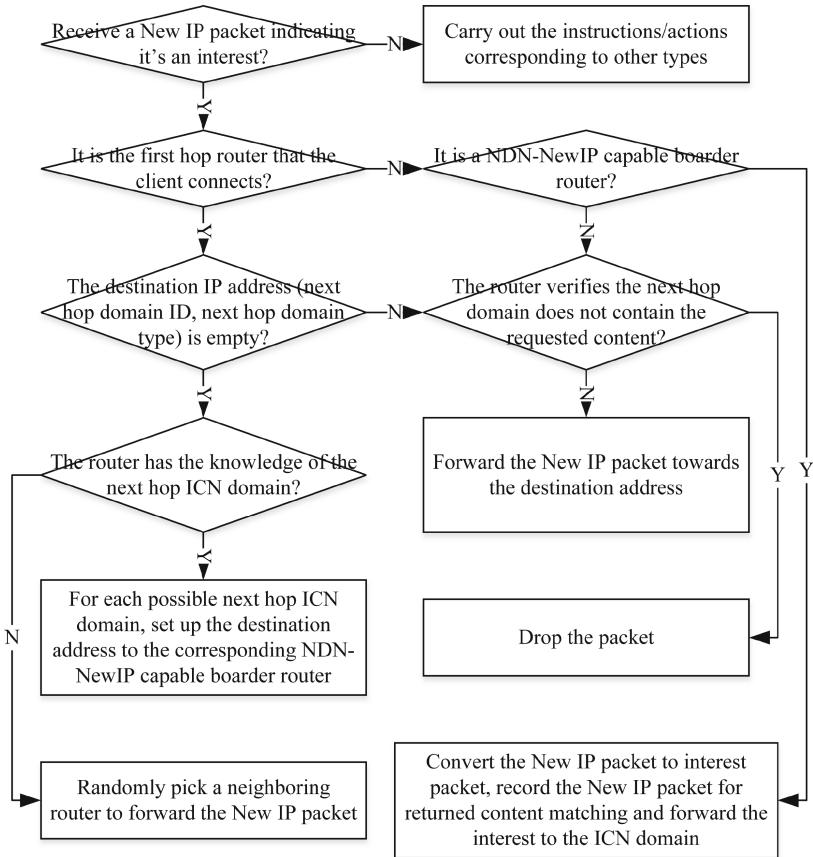
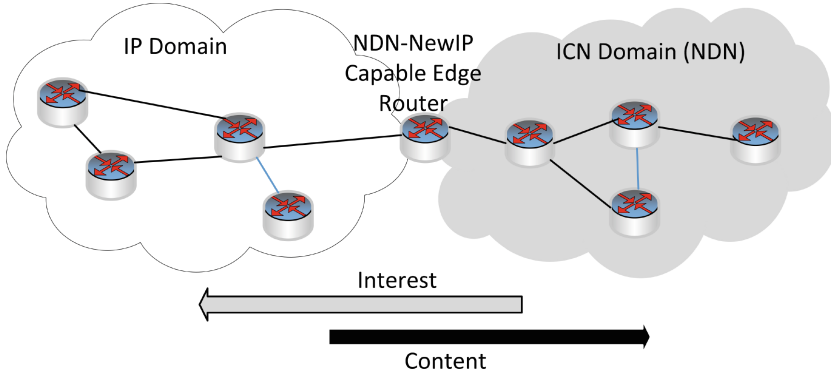


Fig. 5. Procedure taken by routers in the IP domain for the scenario: IP → NDN

### 4.2 NDN → IP

In this section, we discuss another scenario, in which the content requester is located in the NDN domain, while the content provider resides in the IP domain



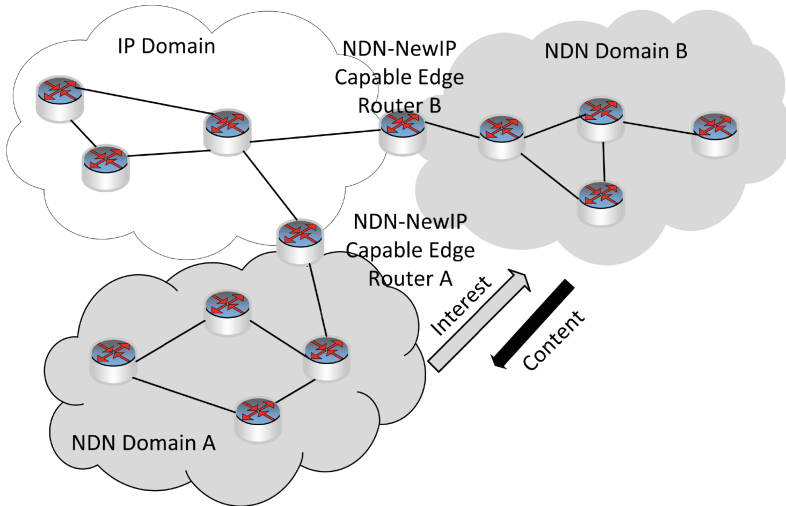
**Fig. 6.** Content request scenario: NDN  $\rightarrow$  IP

as shown in Fig. 6. An interest message is sent from the requester in the NDN domain. If the content is located in the IP domain, the intermediate NDN routers would have maintained FIB entry that directs the interest towards the NDN-NewIP capable edge router. When the interest message reaches the NDN-NewIP capable edge router, it is being converted to a New IP packet with the interest type. On the other hand, the packet could also include other Metadata that is specified in the previous section if the NDN interest message also contain such fields, among which the content name is required, others might be optional. The NDN-NewIP capable edge router would send the request message to content name resolution server, which maintains the content directory in the IP domain. The content name resolution server would return the appropriate content provider based on the content name, the requester's requirements and context. The NDN-NewIP capable edge router would send a content request to the selected content provider on behalf of the requester. The returned content is encapsulated in NDN data packet by the NDN-NewIP capable edge router and forwarded in NDN domain towards the requester.

### 4.3 NDN $\rightarrow$ IP $\rightarrow$ NDN

In this section, we discuss a more complicated scenario, in which the content requester is located in one NDN domain  $A$ , while the content provider resides in another NDN domain  $B$ , as shown in Fig. 7. The two NDN domains are connected by an IP domain. It is essentially a combination of the two scenarios that were discussed in the previous sub-sections. For the first half part, the interest packet is initiated in the NDN domain  $A$  and will reach the NDN-NewIP capable edge router that connects the NDN domain  $A$  and the IP domain, which is denoted as NDN-NewIP Capable Edge Router  $A$ . The NDN-NewIP Capable Edge Router  $A$  would convert the interest message to content request packet by firstly consulting the name resolution server in the IP domain. It finds out the content provider located in another NDN domain  $B$ . The destination address of

the content request packet will be configured to be the NDN-NewIP capable edge router that connects the IP domain and the NDN domain B, which is denoted as NDN-NewIP Capable Edge Router B. The original interest message can be inserted in the IP packet as the payload. The NDN-NewIP Capable Edge Router B would retrieve the original interest message by extracting the payload, and forward in the NDN domain B until it reaches the best content provider. The data packet will firstly reach the NDN-NewIP Capable Edge Router B, which would change the destination address to be the NDN-NewIP Capable Edge Router A. In the NDN domain A, the data packet will follow the reverse path back to the requester by tracing the PIT entries in the intermediate NDN routers.



**Fig. 7.** Content request scenario: NDN  $\rightarrow$  IP  $\rightarrow$  NDN

## 5 Conclusions

The paper proposes to leverage the newly proposed New IP framework to interconnect the NDN domains in the IP ocean. This is a native solution which provides the benefits of asymmetric addressing, performance guarantee for content requests. The paper discusses the various interworking scenarios between ICN domain and IP domain. For the future works, we intend to have a prototyping to show the effectiveness of proposed schemes.

## References

1. Pieter, N., Adrichem, V. N., Lucia, D.: Deploying ICN islands in a sea of IP - The role of interconnection and business models. In: 2017 8th International Conference on the Network of the Future (NOF), pp. 126–128 (2017)
2. PARC: CCNx over UDP. <https://datatracker.ietf.org/meeting/interim-2015-icnrg-04/materials/slides-interim-2015-icnrg-4-5/> (2015)
3. Zuraniewski, P., et al.: Facilitating ICN deployment with an extended openflow protocol. In: Proceedings of the 4th ACM Conference on Information-Centric Networking, pp. 123–133 (2017)
4. Zhang, L., et al.: Named data networking. In: ACM SIGCOMM Computer Communication Review, vol 44, Issue 3, pp 66-73 (2014)
5. Carofiglio, G., et al.: Enabling ICN in the internet protocol: analysis and evaluation of the hybrid-ICN architecture. In: ICN '19: Proceedings of the 6th ACM Conference on Information-Centric Networking, pp. 55-66 (2019)
6. Conti, M., et al.: The road ahead for networking: a survey on ICN-IP coexistence solutions. In: IEEE Communications Surveys & Tutorials, vol. 22, no. 3, pp. 2104-2129 (2020)
7. Dong, L., Wang, G.: Support context-aware IoT content request in Information Centric networks. In: 2016 25th Wireless and Optical Communication Conference (WOCC), pp. 1-4 (2016)
8. Dong, L., Wang, G.: Consumer oriented IoT data discovery and retrieval in information centric networks. In: 2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), pp. 1–7 (2017)
9. Li, R., Makhijani, K., Dong, L.: New IP: A data packet framework to evolve the internet: invited paper. In: 2020 IEEE 21st International Conference on High Performance Switching and Routing (HPSR), pp. 1-8 (2022)
10. Makhijani, K., Dong, L.: Asymmetric addressing structures in limited domain networks. In: 9481811 2021 IEEE 22nd International Conference on High Performance Switching and Routing (HPSR), pp. 1–7 (2021)
11. Li, R., Dong, L., Westphal, C., Makhijani, K.: Qualitative communication for emerging network applications with new IP. In: 2021 17th International Conference on Mobility, Sensing and Networking (MSN), pp. 628-637 (2021)
12. Dong, L., Li, R.: Adaptive network coding based qualitative communication. In: 2022 25th Conference on Innovation in Clouds, Internet and Networks (ICIN), pp. 76-80 (2022)
13. Dong, L., Li, R.: Improve multiple-camera assisted remote driving by qualitative communication and new IP. In: NOMS 2022-2022 IEEE/IFIP Network Operations and Management Symposium, pp. 1–5 (2022)
14. Dong, L., Li, R.: In-Packet Network Coding for Effective Packet Wash and Packet Enrichment. In: 2019 IEEE Globecom Workshops (GC Wkshps), pp. 1–6 (2019)
15. Dong, L., Makhijani, K., Li, R.: Qualitative communication via network coding and new IP : invited paper. In: 2020 IEEE 21st International Conference on High Performance Switching and Routing (HPSR), pp. 1–5 (2020)
16. Dong, L., Li, R.: Optimal chunk caching in network coding-based qualitative communication. In: Digital Communications and Networks, vol. 8, Issue 1, pp. 44-50 (2022)