A Comprehensive Review of Information-Centric Networking: Concepts, Features, Challenges, and Future Scope

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Abstract

Information-Centric Networking changes the paradigm of the Internet from host-based communication to content-based retrieval. The main ideas of this approach are reviewed in this paper: the basic architectures such as CCN and NDN, naming schemes, and the core concepts comprising name-based routing and in-network caching. Moreover, the content-level security model of ICN is emphasized, while open issues concerning scalability and deployment in real-world scenarios are discussed. In general, the paper summarizes current research trends that shape the move toward more efficient and reliable content-centric networks.

1: Introduction

These trends have increasingly exposed the inadequacies of the IP-based Internet, whose primary design focus is the location of hosts rather than information as such. Information-Centric Networking changes this with a content-oriented model, where data is accessed by stable names, rather than host addresses. This architecture enables in-network caching to be truly efficient, provides better support for scalability in terms of increasing demands for content, and inherently offers stronger data-level security

2: Key Concepts of ICN

ICN supplants traditional host-based communications with content-centered data retrieval using persistent names rather than IP addresses. This model enables enhanced mobility, reduced delay, and improved reliability due to the fact that data can be fetched from any node keeping cached copies. ICN offers native security by verifying the data itself, not by relying on secure channels. The naming schemes supported-either hierarchical or flat-offer efficient routing and strong data integrity. In summary, these characteristics make ICN a scalable and effective architecture for modern content delivery, IoT systems, and distributed applications.

2.1 Named Data Networking

NDN shifts communication to a model of asking for data by name, rather than by host address. Without the source location in the request, NDN can perform more flexible routing, ameliorate reliability, and improve the overall user experience.

2.2 Naming of Content

Content naming in Information-Centric Networking is based on either a hierarchical or flat naming structure to uniquely identify data. While hierarchical names allow for name aggregation, thus enhancing routing efficiency, flat names enhance security by embedding self-certifying properties directly into the identifier.

2.3 In-Network Caching

In-network caching is an important ICN feature where routers temporarily save passing data. This allows nearby users to access content directly from the cache instead of the original server. As a result, network traffic decreases, content is delivered faster, and data becomes more easily available.

3. Major ICN Architectures

Numerous frameworks have been suggested for ICN, each employing approaches for naming, routing and data protection. CCN/NDN adopts naming alongside an Interest/Data framework to facilitate caching as well as secure and efficient content distribution. PURSUIT/PSIRP implements a publish-subscribe mechanism grounded in operations and forwarding graphs that support rapid and scalable communication. DONA uses self-certifying names to boost trust and minimize reliance, on central authorities. Each of the designs brings its benefits and trade-offs relative to scalability, routing, security, and deployment. This reflects the overall flexibility of ICN and guides current research toward future integration with the Internet.

3.1 Content-Centric Networking (CCN)

Content-Centric Networking employs hierarchical names to denote information rather than relying on specific server locations.Its fundamental method of communication involves Interest and Data packets: a user transmits an Interest packet, for a named content and the network replies with a Data packet holding that content. This model enables routers to forward requests in the most efficient way possible, in-network storage of content for future reuse, and content retrieval to be more natural and driven by the user—users request the data they want without concern about its location.

3.2 Named Data Networking (NDN)

NDN extends the CCN model with smarter forwarding methods and strong data-centric security where trust is attached directly to the content. Its flexible naming system further improves scalability and reliability of the network.

3.3 PURSUIT/PSIRP

PURSUIT/PSIRP employs the publish–subscribe model where producers publish data and users subscribe to what they need. It relies on rendezvous functions to match subscribers with content and uses efficient forwarding to deliver the data. For this reason, PURSUIT/PSIRP is well-suited to support large and dynamic networks where fast and agile information delivery is required.

3.4 DONA

DONA introduces the concepts of flat, self-certifying names used uniquely to identify data content. The self-certifying properties inherently provide a higher level of built-in security, allowing immediate verification of the origin of data. DONA enables robust name resolution using a dedicated global resolution infrastructure, which maps these flat names efficiently to content locations within the network.

4. Routing and Forwarding in ICN

Routing in ICN and forwarding operate based on content names, not IP addresses. These requests are forwarded to the closest data source, which might be an original server or even a cached one. ICN makes use of hierarchical routing and name aggregation to handle numerous numbers of names efficiently. The smart forwarding strategies, on the other hand, avoid congestion, balance the load, and support mobility. Other features include preventing loops, interest collapsing, and multipath routing for improved speed, reliability, and overall network performance.

4.1 Name-Based Routing

Name-based routing is the core mechanism of ICN, which enables routers to forward requests for content based on the content names themselves, without relying on fixed host addresses, such as IP addresses. This decoupling of content from location allows for efficient data retrieval, often to the nearest copy, enabling highly scalable communication patterns within the network.

4.2 Forwarding Strategies

Performance enhancement in ICN can be achieved by dynamic adaption to network conditions, which enables routers to choose optimal paths and avoid congestion or utilize multipath communication for increased resilience. Major ICN architectural models implement the core ICN principles in different ways. Models such as CCN, NDN, PURSUIT, and DONA differ in their naming schemes, forwarding strategies, and security mechanisms. These different models illustrate the flexibility of ICN and give direction to its deployment on diverse application scenarios.

5. Safety in ICN

Within ICN protection is inherently linked to the content itself (data-centric) than the pathways of communication. This is achieved through essential methods:

1. Verification of Data Authenticity and Integrity: Using signatures every node can confirm the integrity of content regardless of where it originates.

2. Self-asserting names link the identifier to the content's authenticity or its creator to avoid forgery. 3. Cache Poisoning Defense: Ensuring data integrity verifiably stops the addition of counterfeit content, in caches. 4. Interest Flooding Mitigation: Mechanisms such as PIT restrict the number of outstanding requests, protecting against DoS attacks.

6. Applications of ICN

Information-centric networking is appropriate for various modern applications due to its content-centric nature:

• Video Streaming: In-network caching in ICN and efficient content delivery are perfect for latency reduction to provide qualitatively high demanding video streaming.

• IoT and Sensor Networking: ICN simplifies the distribution of data in IoT by retrieving data by name, rather than knowing the location of a specific sensor.

• Vehicular Networks: The resilience of ICN and support for local communications make the exchange of data in dynamic vehicular networks highly reliable.

• Edge Computing: ICN efficiently manages content and computation requests near the user for optimal performance in edge computing environments.

• Disaster Communication Systems: Given the inherent resilience for retrieving content from multiple sources, ICN is robust in disaster communications whenever the infrastructure is damaged.

7. Challenges and Open Research Problems

Although ICN offers benefits it encounters considerable obstacles with several of them representing major unresolved research topics:

• Scalable Name. Routing: Creating effective worldwide systems capable of managing the enormous quantity of content names.

• Cache Management Policies: Determine optimal content replacement strategies in routers.

• Privacy Concerns: Mitigating risks related to user interest exposure through network caches. Deployment Compatibility: Effective integration of the ICN with the existing IP infrastructure.

• Efficient Mobility Support: Ensuring seamless content retrieval for highly mobile devices

8. Future Directions

The following are future pathways that research, on ICN is pursuing to enhance its suitability for next-generation networks.

Integration with 5G/6G Networks:

The ICN will work in conjunction with emerging 5G and 6G technologies by combining rapid low-delay communication, with optimized content access to enable advanced services and applications.

AI-driven forwarding and caching:

It will use Machine Learning techniques to intelligently adjust the forwarding paths and caching strategies in real-time, hence ensuring faster and efficient delivery of data. Stronger yet lighter-weight security mechanisms: New security models beyond simple data signing will be created to address modern threats, ensure trust, and support high mobility in next-generation environments. Edge–Cloud Collaboration via ICN: With ICN, efficient handling of data and workload sharing between the edge devices and cloud systems would be facilitated for better performance with minimal delay.

9. Conclusion

Information-Centric Networking (ICN) redesigns the Internet around data retrieval as opposed to communication between hosts. It facilitates performance enhancement through caching, allows scalability by using name-based routing, and advances security by verification at the data level. Yet, scalable name resolution, integration with today's IP-based systems, and efficient cache management remain open issues that hamper the deployment of such networks. Ongoing research and hybrid ICN–IP deployment approaches will be the main drivers toward making the future Internet more efficient and data-driven.

Reference

1 .Communicating by naming the content, rather than host-based networking, was the idea that Van Jacobson and co-authors (2009) presented in their work.

2. Lixia Zhang and her team gave a tutorial on NDN in detail, which was published in the ACM SIGCOMM Computer Communication Review, 2014.

3.Christian Dannewitz and co-authors (2013) discussed the NetInf architecture, presenting it as a major Information-Centric Networking approach in Computer Communications.

4.T. Koponen et al. presented a data-oriented network architecture in their work at SIGCOMM in 2007.

5.A. Ghodsi et al. (2011) provided a general overview of Information-Centric Networking and its ecosystem during the HotNets workshop.

6. P. Jokela et al. (2009) proposed LIPSIN, a high-speed publish/subscribe networking approach, in their ACM SIGCOMM paper

K. Pentikousis et al. (2016) surveyed ICN architectures, challenges and real-world applications for IEEE Communications Magazine.