

# The Emerging of the Future Internet

Wan Yan Zhengzhou University  
Wei Zhang Zhengzhou University



**Abstract**—In this paper, we discuss researches in the emerging of Future Internet (ICN and NDN). We also talk about edge computing and IoT. We chose these areas because they are hot topics in today research.

## 1 INTRODUCTION

Researchers studied Future Internet, specifically Information-Centric Networking (ICN) and Named Data Networking (NDN) [1]. Their researches are important and we describe existing researches in ICN and NDN in this work. We think that ICN and NDN are the future of the Internet.

## 2 EXISTING RESEARCHES IN ICN AND NDN

### 2.1 Caching

There are many researches in caching in NDN and ICN. In [2], [3], routers in a NDN domain share cached data and coordinate to make caching decisions, entitled cooperative caching, and make it a optimization problem. The Lagrangian relaxation and primal-dual decomposition method is applied to fix the optimization problem into object placement subproblems and object locating subproblems. [4], [5] finds difficult to improve cache efficiency for a distributed approach, thus a lot of cooperative caching methods have been proposed to enhance the cache efficiency. Authors researched a distributed cache management, which is based Push-based Traffic-Aware distributed Cache management (P-TAC). P-TAC improves cache hit rate by using the links having a margin in

a transmission band for push traffic. In [6], [7], researchers show a caching strategy of Named Data Networking that segments each file and spreads them among NDN caches, and: (1) It reduces redundant copies and cache pollution by unpopular content. (2) It reduces the number of futile checks on caches, thus reducing the delay from memory accesses. (3) It increases hit rates in the core without reducing hit rates at the edge (thus improving overall hit rates) and balances the load among caches. (4) It decouples the caches, so there is a simple analytical performance model for the network of caches. Many more works have been done [8], [9], [10]. In [11], [12], solving cache pollution attacks is a prerequisite for the deployment of NDN, which is considered to be the basis for the future Internet and present CoMon++, a framework for lightweight coordination that protects from cache pollution and further attacks in NDN. In [13], [14], normal users take more time to obtain contents due to the attack. There are some countermeasures against cache pollution attack in NDN, but most of them focus on full content names. Using full names needs a large amount of storage cost. In this paper, we propose a cache protection method against cache pollution attack based on hierarchy of content name prefixes in Named Data Networking (CPMH).

### 2.2 Edge Computing

Edge computing and NDN is a hot research field. Researches have been done in edge computing and NDN. In [15], the Building Management Systems (BMS) faces nowadays scalability challenges related to the scale of the

new buildings. Researchers propose approach that combines NDN and edge to provide a scalable, distributed, and optimized solution that can support extreme scale buildings requirements. In [16], [17], the paper discusses three main edge computing challenges, namely service discovery, service invocation, and user mobility management, to highlight NDN's architectural advantages for edge computing systems. In [18], authors implement framework based on architecture and comprises of three main Tiers. The NDN is located at the Tier1 (Things/end devices) and comprises of all the basic functionalities that connect Internet of Things (IoT) devices with Tier 2 (Edge Computing), where we have deployed our Edge node application. The Tier 2 is then further connected with Tier 3 (Cloud Computing), where our Cloud node application is deployed on cloud. In [19], researchers design and prototype Information-Centric edge (ICedge). ICedge runs on top of named-data networking, a realization of the information-centric networking vision, and handles the "low-level" network communication on behalf of applications. ICedge features a fully distributed design that: 1) enables users to get seamlessly onboarded onto an edge network; 2) delivers application invoked tasks to edge nodes for execution in a timely manner; and 3) offers naming abstractions and network-based mechanisms to enable (partial or full) reuse of the results of already executed tasks among users [20].

Algorithms for data reduction in time series (one of the most common types of data in IoT) need to be developed to work posteriori upon big datasets, but they cannot make decisions for each incoming data item. Also the state of the art lacks systems that can apply any of the possible data reduction methods without adding significant delays or major reconfigurations. [21], [22], [23]. In [24], [25], [26], researchers collaborated to talk about the current networking challenges both quantitatively (by analyzing AR/VR network interactions of head-mounted displays) and quantitatively (by distributing a targeted community survey among AR/VR researchers). Enabling ICN with edge computing in Radio Access Net-

work (RAN) can improve the efficiency of content distribution and communication performance by reducing the distance between users and services. In line with this assertion, in this paper, we propose an ICN-capable RAN architecture for 5G edge computing environments that offers device to device communication and ICN application layer support at base stations. Computation reuse has also been explored [27], [28].

### 2.3 Sync and Pub-Sub

In [29], researchers investigate ICN as a publisher-subscriber communication enabler, and present its challenges and limitations. Based on the observations, we propose a group-based subscription architecture, which enables not only a seamless publisher-subscriber model, but also authentication, access control [30], and group management features, without modifying ICN principles. In [31], authors discuss the benefits that a publish/subscribe protocol such as MQTT or its recently proposed enhancement MQTT+ could bring into the picture. However, deploying pub/sub brokers with advanced caching and aggregation functionalities in a distributed fashion poses challenges in protocol design and management of communication resources. In [32], authors researched this problem is caused by a semantic overloading on Sync Interests: a Sync Interest is used both to detect state inconsistency (by embedding the dataset state digest in the Interest name) and to retrieve update (resulting in the update being named under a specific digest). In this report, we first use a simple case study to analyze the behavior of ChronoSync under simultaneous data publications, and then introduce RoundSync, a revision to ChronoSync to fix the overloading problem. In [33], the paper presents a sensor as a service platform to host live content streams (video, data) from a diverse set of input streams including UAVs, city cameras, loop detectors, etc., and to make the data available to a broad range of customers using a novel data dissemination layer. The data-dissemination layer is a content-oriented system based on information-centric networking, a new paradigm that puts content first, and

which inherently enables content mobility and content security (through encryption on demand) [34]. In [35], Content-based networking has been proposed to address such demands with the advantage of increased efficiency, network load reduction, low latency, and energy efficiency. The publish/subscribe (pub/sub) communication paradigm is the most complex and mature example of such a network. Another example is Information Centric Networking (ICN), a global-scale version of pub/sub systems that aims at evolving the Internet from its host-based packet delivery to directly retrieving information by name. In [36], gateways acting as producers need to allocate network resources to send IoT data to consumers. In this paper, it is proposed a Publish/-Subscribe (PubSub) quality of service (QoS) aware framework (PSIoT-Orch) that orchestrates IoT traffic and allocates network resources between aggregates and consumers for massive IoT traffic. PSIoT-Orch schedules IoT data flows based on its configured QoS requirements. Additionally, the framework allocates network resources (LSP/ bandwidth) over a controlled backbone network with limited and constrained resources between IoT data users and consumers [37], [38], [22].

## 2.4 NDN BitTorrent and peer-to-peer

In [39], massive multiplayer online games (MOG) have become increasingly popular over the past decade. Peer-to-peer structures were explored for commercial online games. However, maintaining security and availability while scaling users has driven most multiplayer online games towards a client-server or client-super peer architecture. In [40], [41], peer-to-peer file sharing applications envision a world, where peers will communicate in terms of the data that they are looking for. In this world, peers will be able to retrieve the desired data from any other peer that can provide it, without the need of specifying the location that this data can be found. Some peer-to-peer applications, such as BitTorrent, also provide data-centric security primitives by verifying the integrity of the downloaded data through cryptographic

hashes. However, the current point-to-point TCP/IP network architecture poses a number of challenges to the design and implementation of peer-to-peer systems both in infrastructure-based and mobile ad-hoc networks. Specifically, in infrastructure-based networks, peers have to select others (identified by an IP address) to download data from, estimate the quality of each connection, and constantly try to find peers that can provide higher bandwidth. In [42], it is important to design a network that can maintain a normal service using the remaining network resources, such as base stations and user terminals, even if the central servers are no longer available because of disconnections among servers. [43] present a peer-to-peer application for live streaming of video content encoded at multiple bit rates. The application enables a small set of neighbouring cellular/Wi-Fi devices to increase the quality of video playback by using the Wi-Fi network to share the portion of the live stream downloaded by each peer via the cellular network.

## 2.5 Provider Mobility

In [44], in ICN, name-based addressing and in-network caching allow content to be efficiently distributed/accessed. These properties of ICN have been researched in the arena of wireless domain to implement light-weighted communication protocols. Specifically, researchers present an ICN-based content delivery scheme for Internet-of-Things (IoT), and show how the proposed scheme support seamless hand-off. In [45], the mobility support for ICN was generally divided into three categories, the consumer mobility, producer mobility and network mobility. Producer mobility is the support for the mobile content provider, source or producer to relocate without disrupting content consumer and intermediate router for content name and its location. Researchers reviews an analysis of producer mobility support in some popular ICN approaches and summarizes some of its features, which provide support during mobility. In [46], [47], [48], the Broadcasting Approach is proposed as a solution to the problem of the mobile producer in NDN. Consequently,

the result may solve the inherited problems of triangular routing in NDN network mobility and have significant implication to support the integration of 5G, Mobile Ad hoc Networks (MANET), Delay-Tolerant Network, Vehicular Ad hoc Networks (VANET).

## 2.6 Simulation Tool

In [49], [50], despite this wide interest in ICN, there is a shortage of publicly-available tools suitable for evaluating the performance of caching systems effectively. In fact, all available simulators or emulators are either bound to a specific architecture or cannot execute simulations at the scale required and within a reasonable time-frame. To address these issues, we present Icarus, a Python-based caching simulator for ICN. Icarus allows users to evaluate caching strategies for any ICN implementation and also provides modelling tools useful for caching research. NDNsim is popular simulation for NDN.

## 3 CONCLUSIONS

We presented researches done by researchers in Information-Centric Networking (ICN) and Named Data Networking (NDN). These researches presented in categories to inform community about them. In future, we will research more works and present them to others, and develop trends in future internet for ICN and NDN.

## REFERENCES

- [1] George Xylomenos et al. A survey of information-centric networking research. *IEEE communications surveys & tutorials*, 16(2):1024–1049, 2013.
- [2] Xiaoyan Hu and Jian Gong. Distributed in-network cooperative caching. In *2012 IEEE 2nd International Conference on Cloud Computing and Intelligence Systems*, volume 2, pages 735–740. IEEE, 2012.
- [3] Sifat Ut Taki and Spyridon Mastorakis. An ndn-enabled fog radio access network architecture with distributed in-network caching. *arXiv preprint arXiv:2301.08564*, 2023.
- [4] Kenta Mori, Takashi Kamimoto, and Hiroshi Shigeno. Push-based traffic-aware cache management in named data networking. In *2015 18th International Conference on Network-Based Information Systems*, pages 309–316. IEEE, 2015.
- [5] Satyanarayana Vusirikala, Spyridon Mastorakis, Alexander Afanasyev, and Lixia Zhang. Hop-by-hop best effort link layer reliability in named data networking. Technical report, NDN, Technical Report, NDN-0041, 2016.
- [6] Mostafa Rezazad and YC Tay. Ccndns: A strategy for spreading content and decoupling ndn caches. In *2015 IFIP Networking Conference (IFIP Networking)*, pages 1–9. IEEE, 2015.
- [7] Kevin Chan, Bongjun Ko, Spyridon Mastorakis, Alexander Afanasyev, and Lixia Zhang. Fuzzy Interest Forwarding. In *Proceedings of the Asian Internet Engineering Conference*, pages 31–37. ACM, 2017.
- [8] Junjie Xu, Kaiping Xue, Chengbao Cao, and Hao Yue. Incentive cooperative caching for localized information-centric networks. In *2017 9th International Conference on Wireless Communications and Signal Processing (WCSP)*, pages 1–6. IEEE, 2017.
- [9] Leanna Vidya Yovita and Nana Rachmana Syambas. Caching on named data network: a survey and future research. *International Journal of Electrical & Computer Engineering* (2088-8708), 8, 2018.
- [10] Samar Shailendra et al. Performance evaluation of caching policies in ndn-an icn architecture. In *2016 IEEE Region 10 Conference (TENCON)*, pages 1117–1121. IEEE, 2016.
- [11] Hani Salah, Mohammed Alfatafta, Saed SayedAhmed, and Thorsten Strufe. Comon++: Preventing cache pollution in ndn efficiently and effectively. In *2017 IEEE 42nd Conference on Local Computer Networks (LCN)*, pages 43–51. IEEE, 2017.
- [12] Spyridon Mastorakis and Abderrahmen Mtibaa. Towards service discovery and invocation in data-centric edge networks. In *2019 IEEE 27th International Conference on Network Protocols (ICNP)*, pages 1–6. IEEE, 2019.
- [13] Takashi Kamimoto, Kenta Mori, Sayaka Umeda, Yuri Ohata, and Hiroshi Shigeno. Cache protection method based on prefix hierarchy for content-oriented network. In *2016 13th IEEE Annual Consumer Communications & Networking Conference (CCNC)*, pages 417–422. IEEE, 2016.
- [14] Adrian-Cristian Nicolaescu, Spyridon Mastorakis, and Ioannis Psaras. Store edge networked data (send): A data and performance driven edge storage framework. In *IEEE INFOCOM 2021-IEEE Conference on Computer Communications*, pages 1–10. IEEE, 2021.
- [15] Junior Dongo, Ludovic Foltete, Charif Mahmoudi, and Fabrice Mourlin. Distributed edge solution for iot based building management system with ndn. In *2019 Global Information Infrastructure and Networking Symposium (GIIS)*, pages 1–5. IEEE, 2019.
- [16] Jonathan Lee, Abderrahmen Mtibaa, and Spyridon Mastorakis. A case for compute reuse in future edge systems: An empirical study. In *2019 IEEE Globecom Workshops (GC Wkshps)*, pages 1–6. IEEE, 2019.
- [17] Spyridon Mastorakis, Tianxiang Li, and Lixia Zhang. Dapes: Named data for off-the-grid file sharing with peer-to-peer interactions. *arXiv preprint arXiv:2006.01651*, 2020.
- [18] Rehmat Ullah, Muhammad Atif Ur Rehman, and Byung-Seo Kim. Design and implementation of an open source framework and prototype for named data networking-based edge cloud computing system. *IEEE Access*, 7:57741–57759, 2019.
- [19] Spyridon Mastorakis, Abderrahmen Mtibaa, Jonathan Lee, and Satyajayant Misra. ICedge: When Edge Computing Meets Information-Centric Networking. *IEEE Internet of Things Journal*, 2020.
- [20] Md Washik Al Azad, Susmit Shannigrahi, Nicholas Stergiou, Francisco R Ortega, and Spyridon Mastorakis.

- Cledge: A hybrid cloud-edge computing framework over information centric networking. In *2021 IEEE 46th Conference on Local Computer Networks (LCN)*, pages 589–596. IEEE, 2021.
- [21] Kusumlata Jain and Smaranika Mohapatra. Taxonomy of edge computing: Challenges, opportunities, and data reduction methods. In *Edge Computing*, pages 51–69. Springer, 2019.
- [22] Mian Ahmad Jan, Muhammad Zakarya, Muhammad Khan, Spyridon Mastorakis, Varun G Menon, Venki Balasubramanian, and Ateeq Ur Rehman. An ai-enabled lightweight data fusion and load optimization approach for internet of things. *Future Generation Computer Systems*, 122:40–51, 2021.
- [23] Spyridon Mastorakis, Andreas Skiadopoulos, Susmit Shannigrahi, Aaron Likens, Boubakr Nour, and Nicholas Stergiou. Networking and computing in biomechanical research: Challenges and directions. *IEEE Communications Magazine*, 59(6):103–109, 2021.
- [24] Susmit Shannigrahi, Spyridon Mastorakis, and Francisco R Ortega. Next-generation networking and edge computing for mixed reality real-time interactive systems. In *2020 IEEE International Conference on Communications Workshops (ICC Workshops)*, IEEE, 2020.
- [25] Boubakr Nour et al. Compute-less networking: Perspectives, challenges, and opportunities. *IEEE network*, 34(6):259–265, 2020.
- [26] Aaron D Likens, Spyridon Mastorakis, Andreas Skiadopoulos, Jenny A Kent, Md Washik Al Azad, and Nick Stergiou. Irregular metronomes as assistive devices to promote healthy gait patterns. In *2021 IEEE 18th Annual Consumer Communications & Networking Conference (CCNC)*, pages 1–7. IEEE, 2021.
- [27] Md Washik Al Azad and Spyridon Mastorakis. The promise and challenges of computation deduplication and reuse at the network edge. *IEEE Wireless Communications*, 2022.
- [28] Md Washik Al Azad and Spyridon Mastorakis. Reservoir: Named data for pervasive computation reuse at the network edge. In *2022 IEEE International Conference on Pervasive Computing and Communications (PerCom)*, pages 141–151. IEEE, 2022.
- [29] Boubakr Nour, Kashif Sharif, Fan Li, Song Yang, Hassine Moun gla, and Yu Wang. Icn publisher-subscriber models: Challenges and group-based communication. *IEEE Network*, 33(6):156–163, 2019.
- [30] Boubakr Nour, Hakima Khelifi, Rasheed Hussain, Spyridon Mastorakis, and Hassine Moun gla. Access control mechanisms in named data networks: A comprehensive survey. *ACM Computing Surveys (CSUR)*, 54(3):1–35, 2021.
- [31] Alessandro EC Redondi, Andrés Arcia-Moret, and Pietro Manzoni. Towards a scaled iot pub/sub architecture for 5g networks: The case of multiaccess edge computing. In *2019 IEEE 5th World Forum on Internet of Things (WF-IoT)*, pages 436–441. IEEE, 2019.
- [32] Pedro de-las Heras-Quirós et al. The design of RoundSync protocol. Technical report, Technical Report NDN-0048, NDN, 2017.
- [33] Ali Shariat, Ali Tizghadam, and Alberto Leon-Garcia. An icn-based publish-subscribe platform to deliver uav service in smart cities. In *2016 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*, pages 698–703. IEEE, 2016.
- [34] Boubakr Nour et al. Information-centric networking in wireless environments: Security risks and challenges. *IEEE Wireless Communications*, 28(2):121–127, 2021.
- [35] Mihaela Ion. *Security of publish/subscribe systems*. PhD thesis, University of Trento, 2013.
- [36] Pedro Moraes, Rafael Reale, and Joberto Martins. A publish/subscribe qos-aware framework for massive iot traffic orchestration. *arXiv preprint arXiv:1806.03157*, 2018.
- [37] Rama Krishna Thelagathoti, Spyridon Mastorakis, Anant Shah, Harkeerat Bedi, and Susmit Shannigrahi. Named data networking for content delivery network workflows. In *2020 IEEE 9th International Conference on Cloud Networking (CloudNet)*, pages 1–7. IEEE, 2020.
- [38] Robert Thompson, Eric Lyons, Ishita Dasgupta, Spyridon Mastorakis, Michael Zink, and Susmit Shannigrahi. An information centric framework for weather sensing data. *arXiv preprint arXiv:2203.14426*, 2022.
- [39] Zhehao Wang, Zening Qu, and Jeff Burke. Demo overview-matryoshka: design of ndn multiplayer online game. In *Proceedings of the 1st ACM Conference on Information-Centric Networking*, pages 209–210, 2014.
- [40] Spyridon Mastorakis. *Peer-to-peer data sharing in named data networking*. PhD thesis, UCLA, 2019.
- [41] Yar Muhammad, Mian Ahmad Jan, Spyridon Mastorakis, and Bakht Zada. A deep learning-based smart assistive framework for visually impaired people. In *2022 IEEE International Conference on Omni-layer Intelligent Systems (COINS)*, pages 1–6. IEEE, 2022.
- [42] Takeo Ogawara, Yoshihiro Kawahara, and Tohru Asami. Information dissemination performance of a disaster-tolerant ndn-based distributed application in disrupted cellular networks. In *Peer-to-Peer Computing (P2P)*, 2013 *IEEE Thirteenth International Conference on*, pages 1–5. IEEE, 2013.
- [43] Andrea Detti, Bruno Ricci, and Nicola Blefari-Melazzi. Mobile peer-to-peer video streaming over information-centric networks. *Computer Networks*, 81:272–288, 2015.
- [44] Donghyeok An and Dohyung Kim. Icn-based lightweight mobility support in iot. In *2018 27th International Conference on Computer Communication and Networks (ICCCN)*, pages 1–2. IEEE, 2018.
- [45] Muktar Hussaini, Shahrudin Awang Nor, and Amran Ahmad. Producer mobility support for information centric networking approaches: A review. *Int. J. Appl. Eng. Res*, 13(6):3272–3280, 2018.
- [46] Muktar Hussaini, Shahrudin Awang Nor, Habeeb Bello-Salau, Hiba Jasim Hadi, Aminu Abbas Gumel, and Kabiru Abdullahi Jahun. Mobility support challenges for the integration of 5g and iot in named data networking. In *2019 2nd International Conference of the IEEE Nigeria Computer Chapter (NigeriaComputConf)*, pages 1–7. IEEE, 2019.
- [47] Mian Ahmad Jan, Fazlullah Khan, Spyridon Mastorakis, Muhammad Adil, Aamir Akbar, and Nicholas Stergiou. Lightiot: Lightweight and secure communication for energy-efficient iot in health informatics. *IEEE transactions on green communications and networking*, 5(3):1202–1211, 2021.
- [48] Boubakr Nour, Spyridon Mastorakis, and Abderrahmen Mtibaa. Whispering: Joint service offloading and computation reuse in cloud-edge networks. In *ICC 2021-IEEE International Conference on Communications*, pages 1–6. IEEE, 2021.
- [49] Lorenzo Saino, Ioannis Psaras, and George Pavlou. Icarus: a caching simulator for information centric networking (icn). In *SimuTools*, volume 7, pages 66–75. ICST, 2014.
- [50] Zouhir Bellal et al. Coxnet: A computation reuse architecture at the edge. *IEEE Transactions on Green Communications and Networking*, 5(2):765–777, 2021.