重慶郵電大學
CHONGQING UNIVERSITY OF POSTS AND TELECOMMUNICATIONS

2021年第四届信息中心未来网络学术会议(IEEE HotICN 2021)

NDN网络架构的演进
Evolution of NDN Architecture

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（雒 江 涛）

2021.11.26 南京 virtual

目录 Contents

1. Background

- Why NSF start FIA research 10 years before ?

"As our reliance on a secure and highly dependable information technology infrastructure continues to increase, it is no longer clear that emerging and future needs of our society can be met by the current trajectory of incremental changes to the current Internet."

"Thus our call to the research community to propose new Internet architectures that hold promise for the future."

---- Ty Znati, director of the Computer and Network Systems Division, NSF

NDN, **MobilityFirst**, **Nebula**, and **XIA** were awarded.

NSF Announces Future Internet Architecture Awards, NSF News Release 10-156, August 27, 2010

1. Background

❑ Named Data Networking (NDN)

- Born from Content Centric Networking (CCN)
- Vision:
  - **Information-intensive business** (travel, banks, etc.) moved onto the Internet.
  - an ever-increasing range of content can be distributed digitally.
  - The **Web** makes it easy for anyone to create, discover and consume content
  - **hardware advances** makes it feasible to connect everything to the Internet
  - the most predominant use of the Internet is centered on *content creation, dissemination and delivery*, and this trend will continue into the foreseeable future.
- Core ideas:
  - Focus changed from "**where**" (address) to "**what**" (content)
  - **Named data** as the first-class entity/citizen

Van Jacobson (1950-)

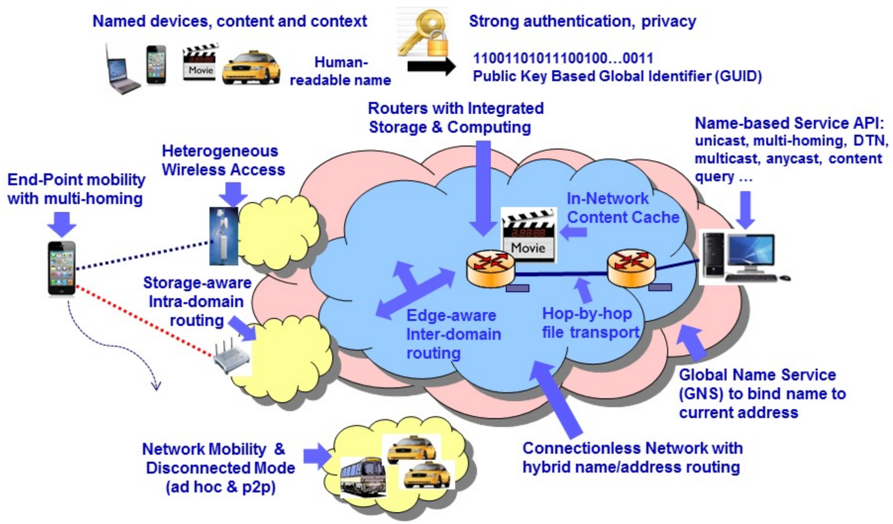
Lixia Zhang (1951-)

NDN Project, TR NDN-0001, Oct 2010

1. Background

❑ MobilityFirst (MF)

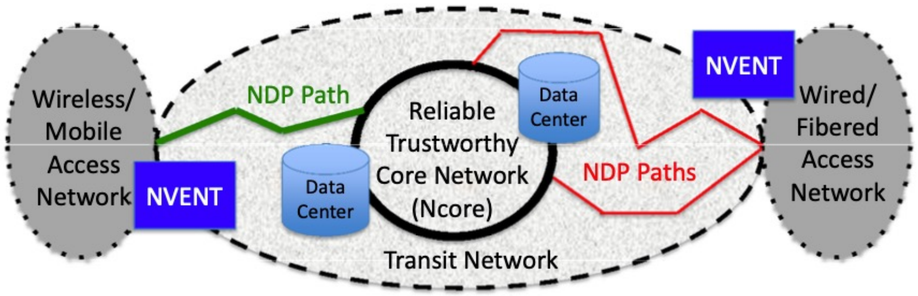
- Vision
  - ◆ **Mobility** as the Key driver for the future Internet
  - ◆ Internet → **mobile Internet** (cell phones, embedding devices, vehicular networks, …)
  - ◆ **Mobility as norm**
- Core features
  - ◆ Named objects are assigned a secure public key GUID
  - ◆ Global Name Resolution & Routing Services
  - ◆ Storage-aware routing
  - ◆ Hop-by-hop (segmented) transport
  - ◆ Separate mgmt. plane

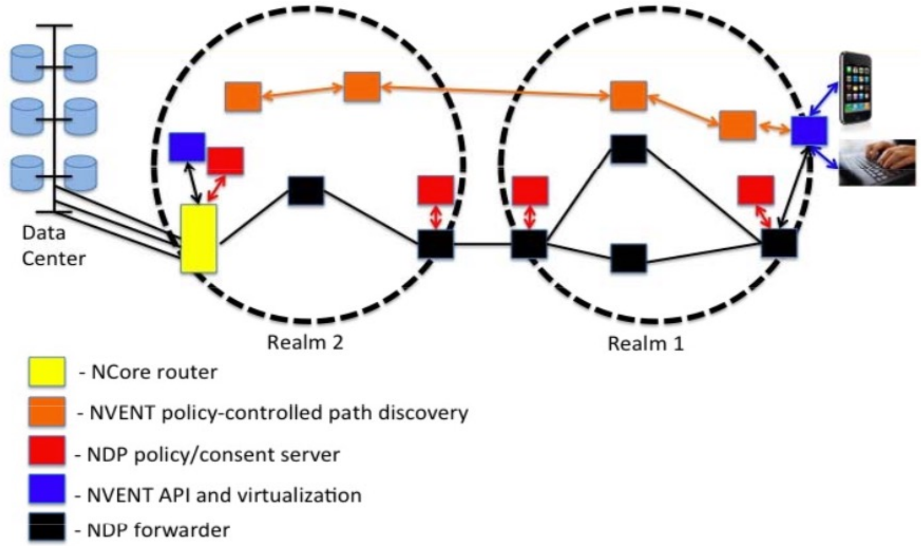


http://mobilityfirst.winlab.rutgers.edu/Index.html

❑NEBULA

- Nebula is Latin for cloud.
- Vision
  - ◆ cloud computing will comprise an increasing fraction of the application workload offered to an Internet.
  - ◆ access to cloud computing resources will demand new architectural features from a network.
- Core features
  - ◆ NEBULA Core Architecture (NCore): high performance, ultra-reliable router
  - ◆ NEBULA Data Plane (NDP)
  - ◆ NEBULA extensible control plane (NVENT)

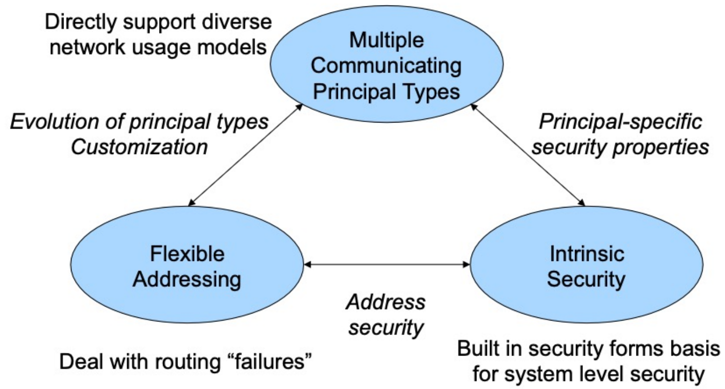


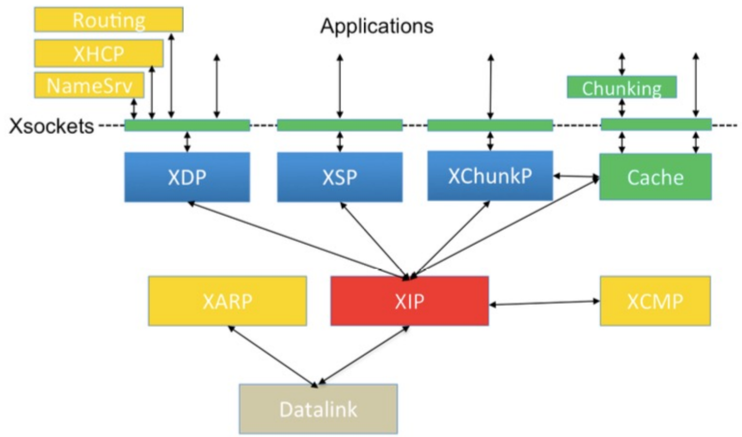


A brief overview of the NEBULA future Internet Architecture, ACM SIGCOMM CCR, 2014

1. Background

- eXpressive Internet Architecture (XIA)
  - Vision
    - Growing **diversity** of network use models
    - Need of trustworthy communication
    - Growing set of stakeholders
  - Key features
    - explicitly support communication between diverse entities, i.e., principal (hosts, services, content, future additional entities), identified by different kinds of XIDs
    - Intrinsic security
    - Flexible addressing, using Directed Acyclic Graphs (DAGs) of XIDs





XIA: Architecting a More Trustworthy and Evolvable Internet, ACM SIGCOMM CCR, 2014

1. Background

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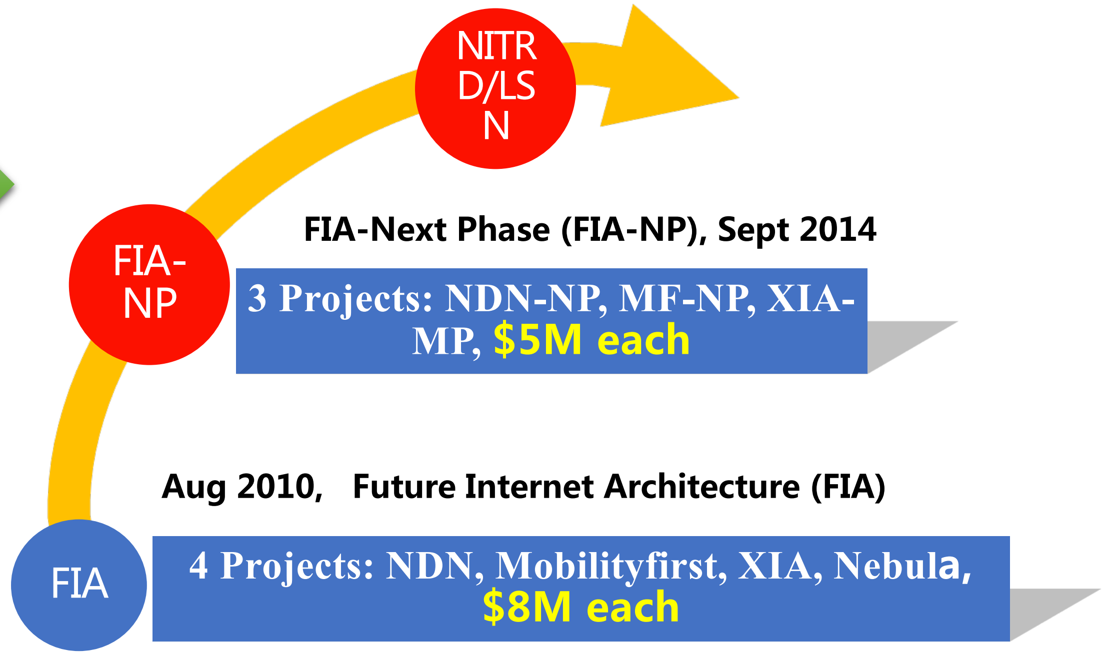
US	NSF 2005, FIND Project（Future Internet Design）
	May 2007 Global Environment for Network Innovations, GENI
	2010 FIA计划（Future Internet Architecture），2014 FIA-NP 2020 NITRD (Networking and Information Technology Research and Development)，LSN (Large Scale Networking)
EU	FP7 2008/Horizon 2020 FIRE Project（Future Internet Research and Experiment）
	2016, Horizon 2020-Secure societies Plan
Japan	2013, GreenICN, by NICT Japan and EU FP7: Disaster, video delivery, energy-efficient
ITU	2018, Network 2030 Focus Group

NSF FIA → FIA-NP → NITRD/LSN



Research Projects abroad on Future Networks

《全球未来网络发展白皮书》2020

1. Background

服务定制网络（SCN）

智慧标识网络

New IP

全维可定义网络

双结构网络

地址驱动网络

多模态网络

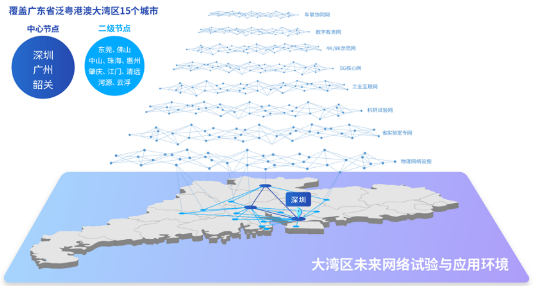
国家科技计划、新基建、创新土壤、经济实力

Representative architectures Proposal of Future Network in China

《全球未来网络发展白皮书》 2020

National Testbed

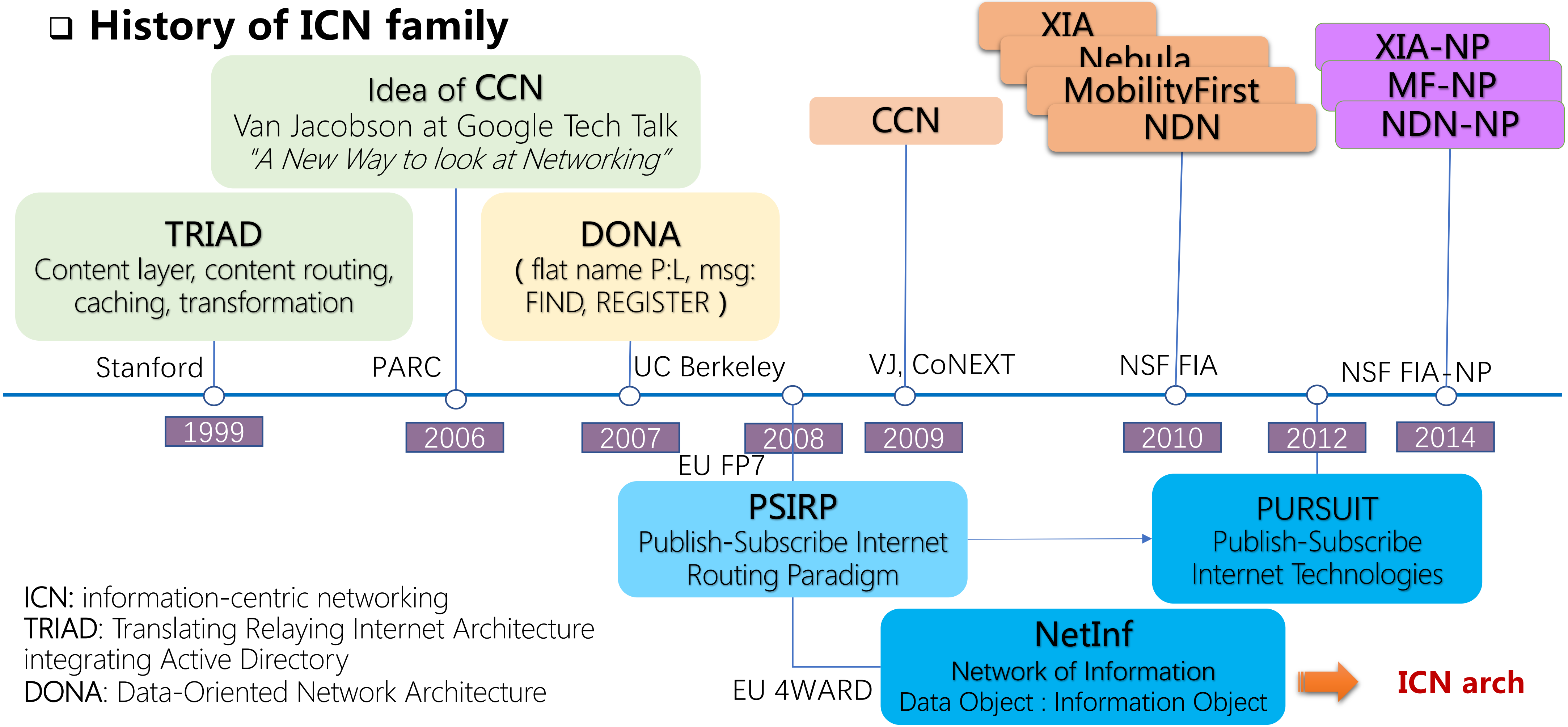
CENI 启动



大湾区未来网络试验与应用环境（鹏城实验室）

1. Background

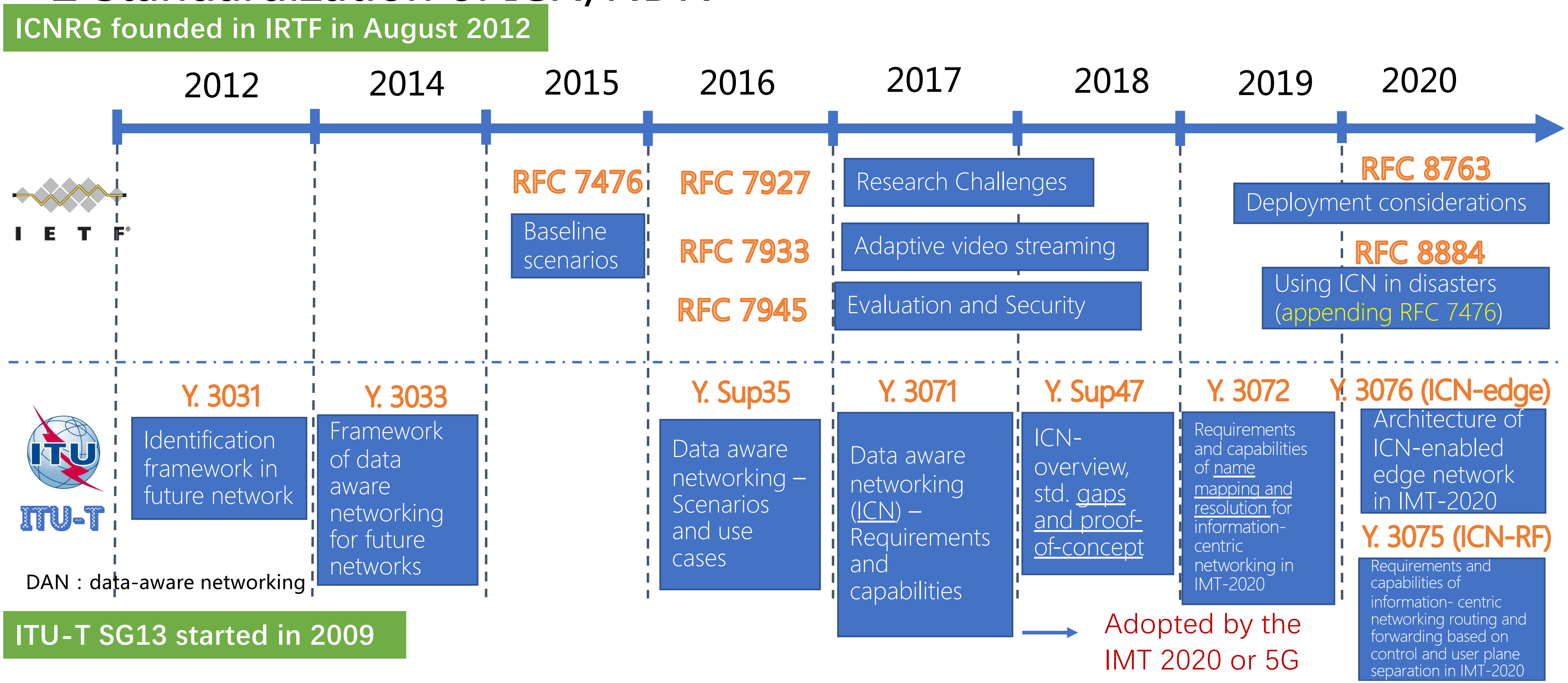
❑ History of ICN family



ICN: information-centric networking
TRIAD: Translating Relaying Internet Architecture integrating Active Directory
DONA: Data-Oriented Network Architecture

1. Background

❑ Standardization of ICN/NDN



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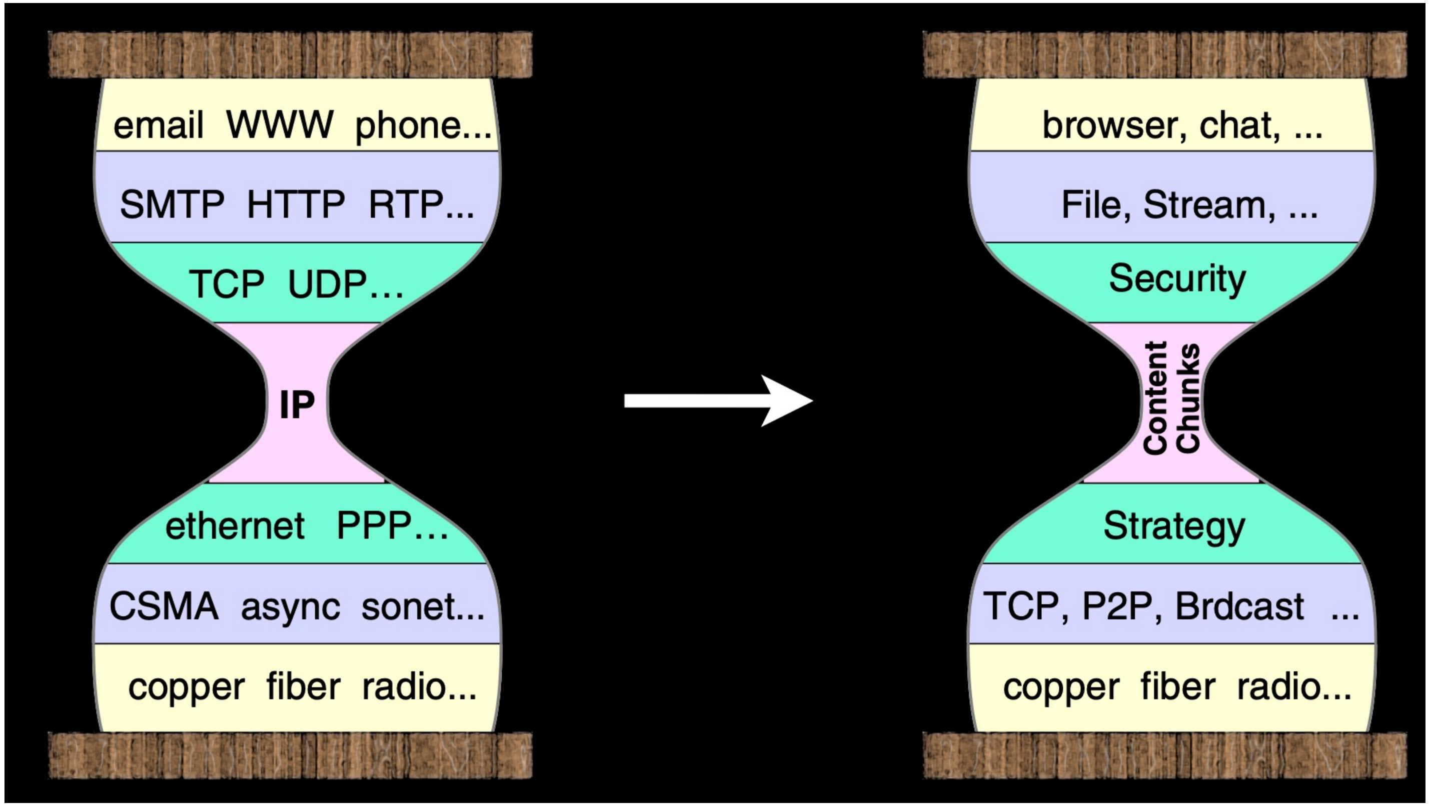
2. NDN architecture overview

- Named Data is the *'first-class citizen'*
  - Each piece of Data has a unique name, independent of location.
  - Named data oriented
- Name-based addressing & routing
  - Decoupling of Named Data and its location
- In-network storage/caching
- Data-centric security
  - Each Data packet is signed by its producer

- *Consumer-driven Pull*
  - A consumer sends an Interest packet to request a named Data packet.
  - Without notification mechanism
  - Push not allowed
- *Symmetric Interest/Data path*
  - The matching Data packet goes back on the reverse path of its corresponding Interest packet.
- *Stateful forwarding*
  - Recording sources of requests

Core features of NDN design

2. NDN architecture overview



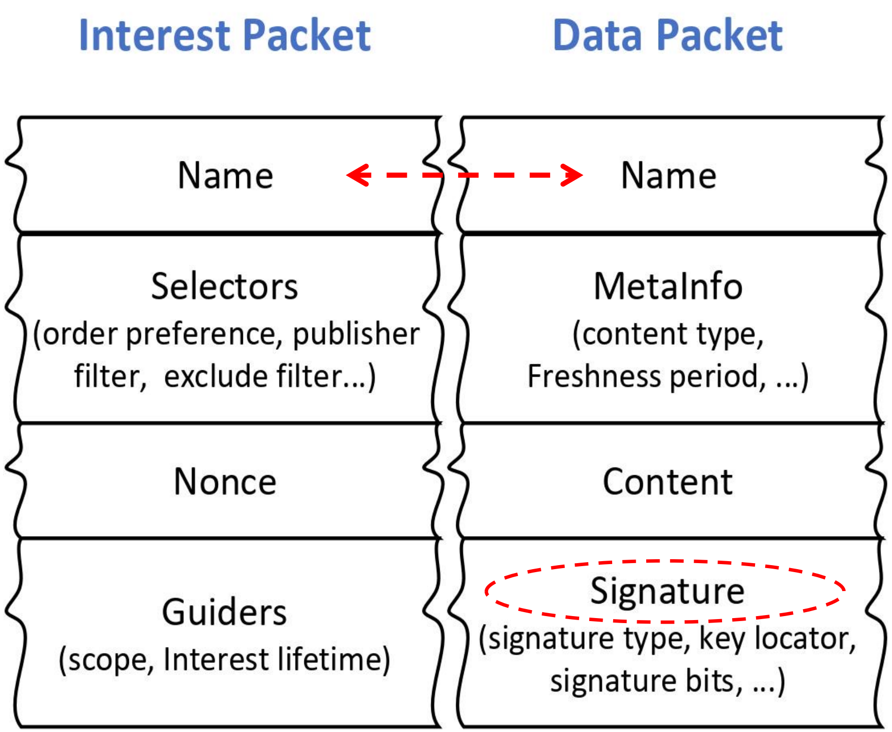
The new 'hourglass' model

Content Chunks, or named Data Chunks as the narrow waist of NDN/CCN

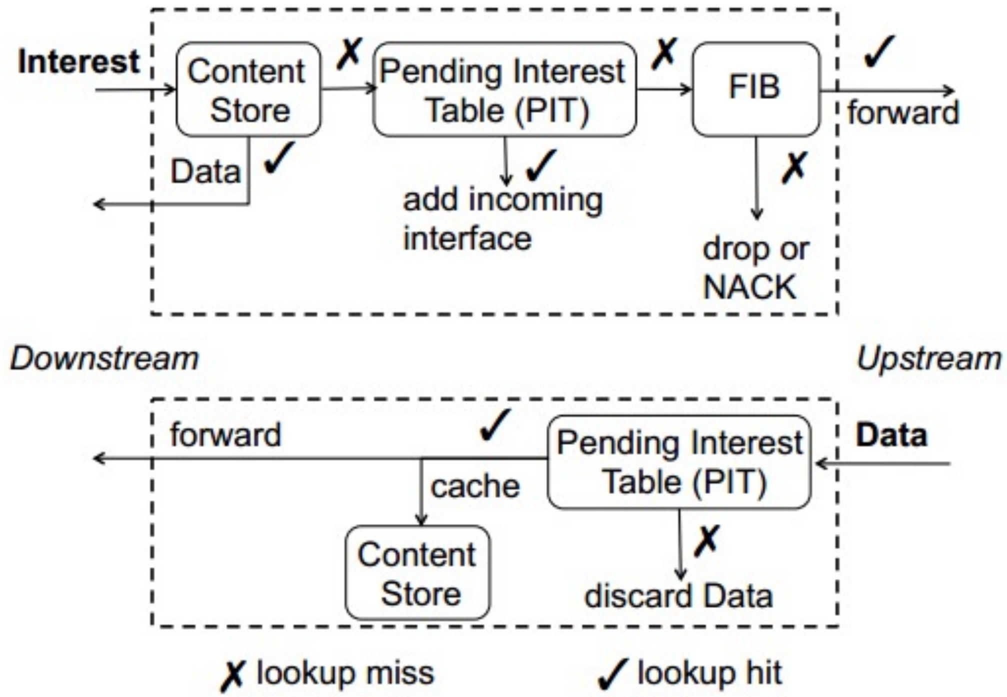
Down HTTP to the network layer (only 'GET' method)

Van Jacobson, Introduction to Content Centric Networking, June 2009.

2. NDN architecture overview



NDN packet format

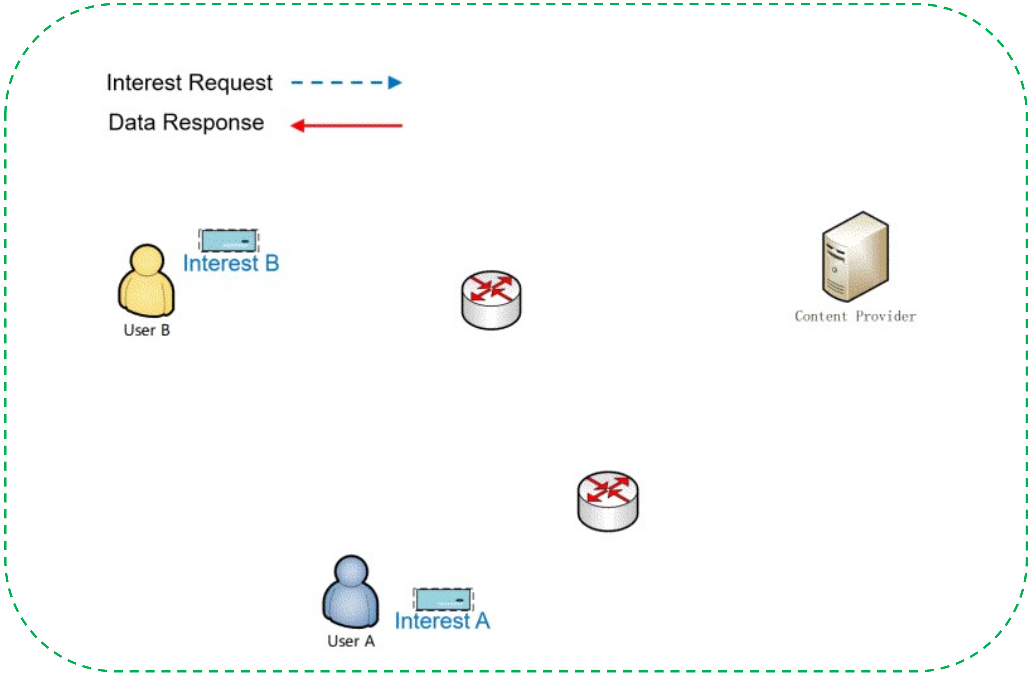


Forwarding Process at an NDN router

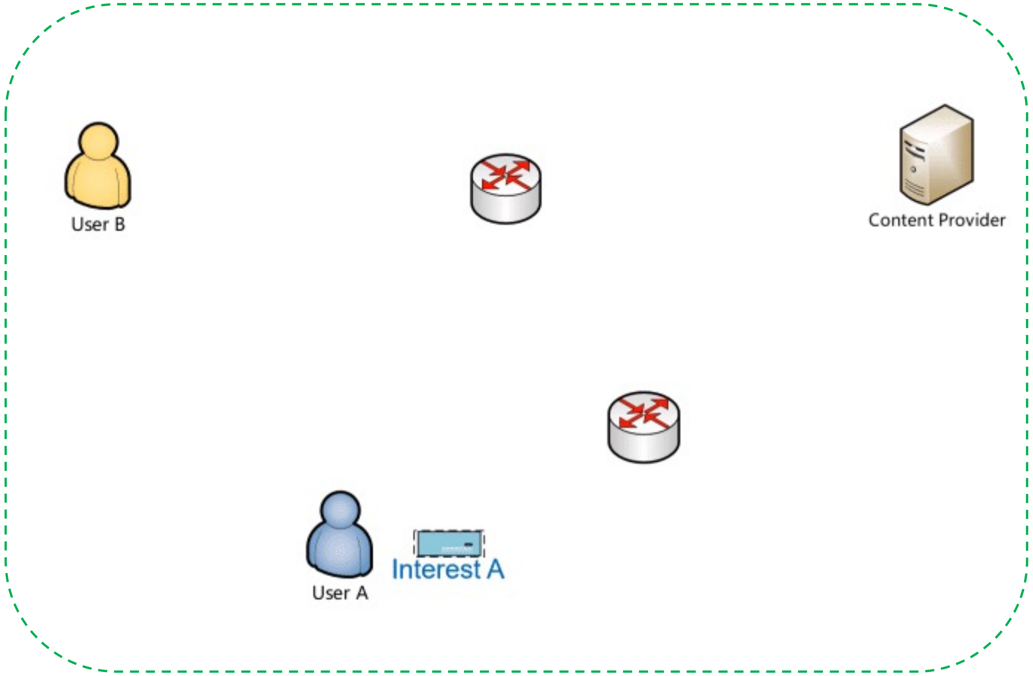
Packet format and forwarding process

Lixia Zhang, Named Data Networking, ACM SIGCOMM CCR, 2004.

Advantages of NDN architecture



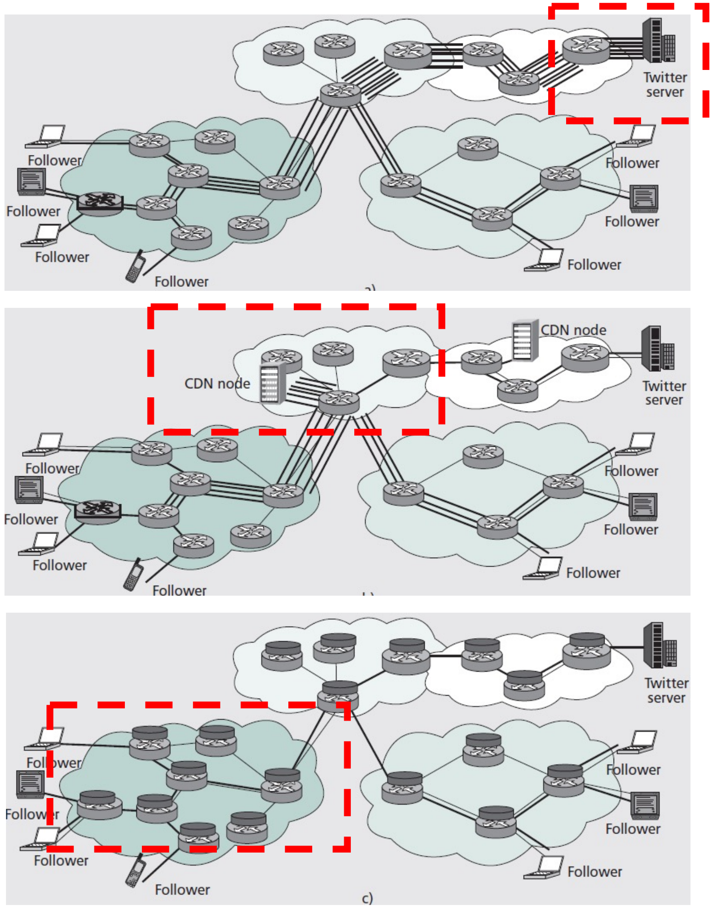
(a) Multicast data delivery via PIT aggregation



(b) In-network caching

- Natural multicast: Interest aggregation at PIT reduces duplicate Interest packets； stateful forwarding enables multicast naturally.
- Bandwidth efficiency: In-network caching reduces backbone bandwidth utilization.

Advantages of NDN architecture



（a） **IP network**：consumers get content from servers directly

- There are a large number of repeated (redundant) transmissions in network leading to serious waste of resources.

（b）**CDN**（Content Distribution Network）：consumers get content from CDN nodes

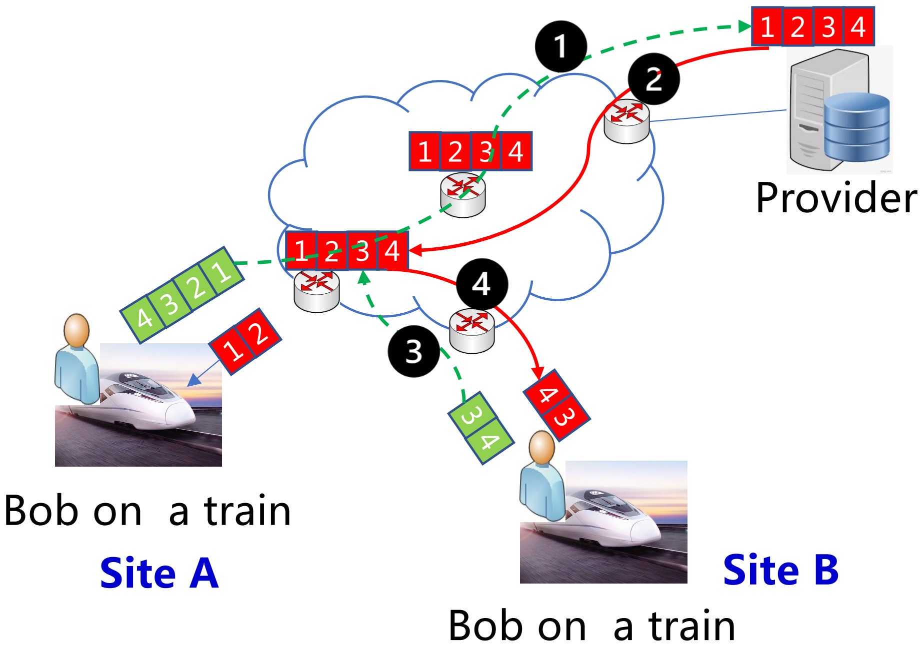
- Many caching servers are distributed in the areas where the request is intensive. When users visit the website, they will be redirected to the nearest server.

（c）**ICN**（Information-Centric Network）： consumers get content from ICN nodes

- In-network caching: Every node in ICN can cache data. Every node can provide content for other nodes if it has cached the content others need.

The bandwidth consumption for ICN is the lowest.

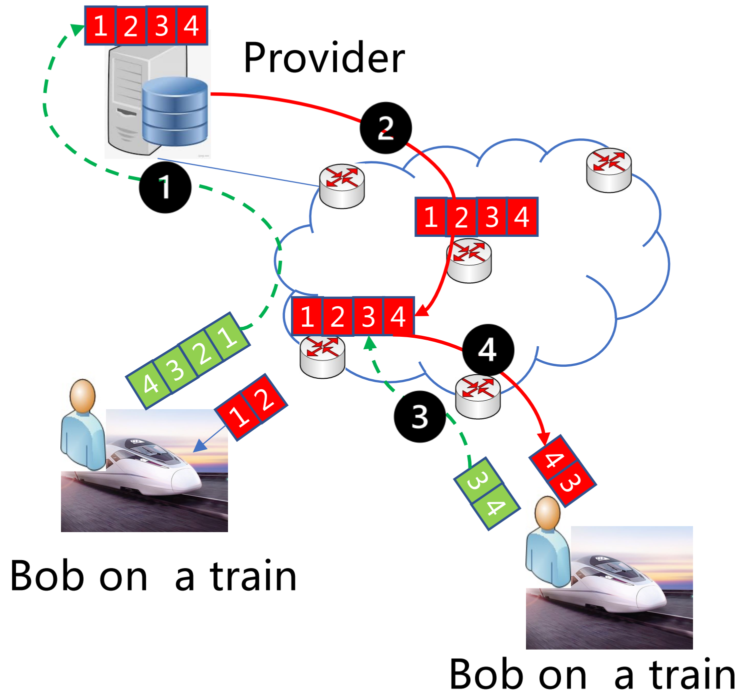
Advantages of NDN architecture



Just re-issue requests for those unreached Data packets to the nearby routers.

- **In-network caching**

Consumer mobility, content mobility



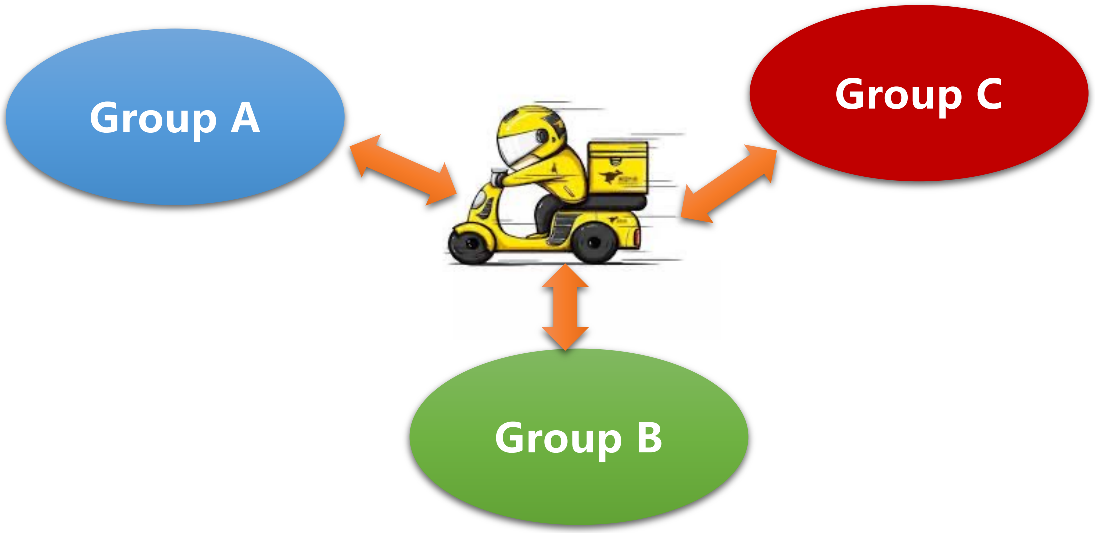
Just re-route the requests.

- **Data names independent of location**

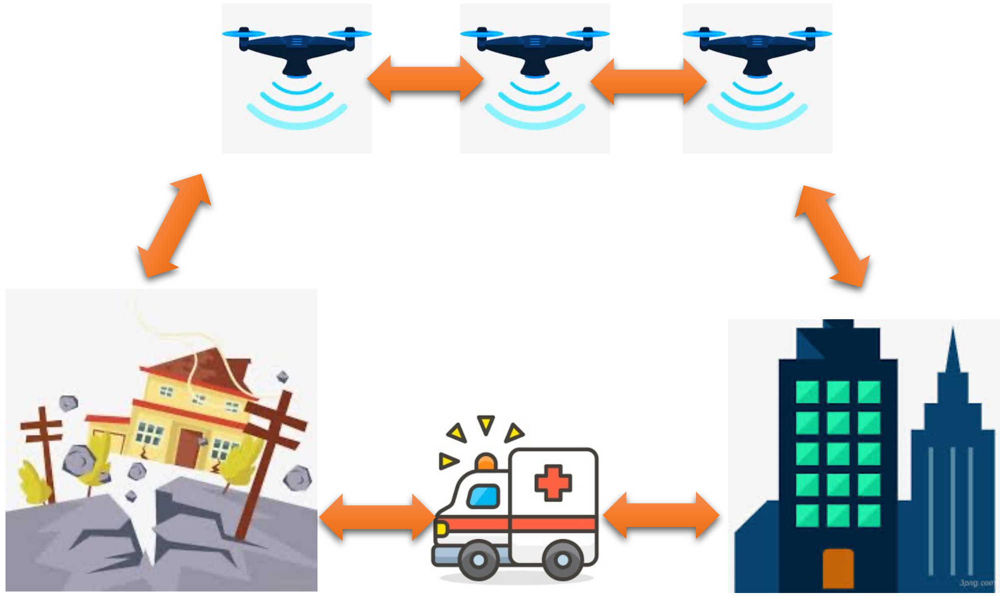
Producer/provider mobility

Advantages of NDN architecture

Data mule / Network mobility



Opportunistic routing for intermittent links

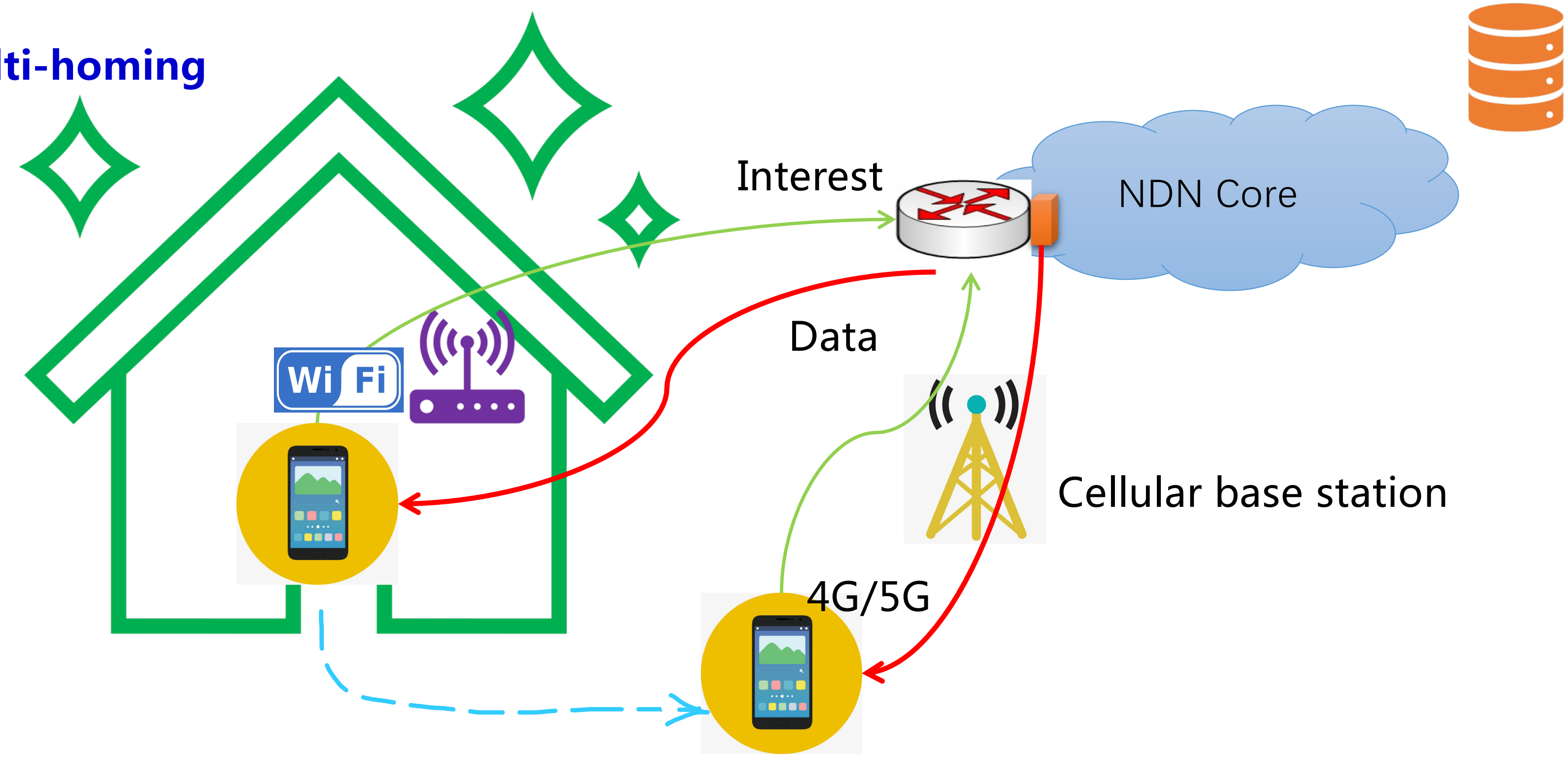


Connecting isolating islands
Under instable power, network, … …

- **Connectionless data delivery**
- **In-network storage**

Advantages of NDN architecture

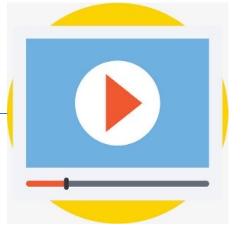
Natural multi-homing



- Each phone has multiple network interface; each has an IP address. Handover in TCP/IP between them results in connection failure.
- Connectionless data fetching in NDN is independent on interfaces.

NDN-enabled application scenarios

NDN typical applications



Content dissemination

- Content based addressing
- Traffic aggregation
- In-network caching

Vehicular Networks

- connectionless data delivery
- In-network caching
- Data mule

Internet of Things

- connectionless = unlimited connections

Delay/Disruption Tolerance Network

- Emergency supporting & disaster recovery
  - Infrastructure free communications
- Opportunistic routing

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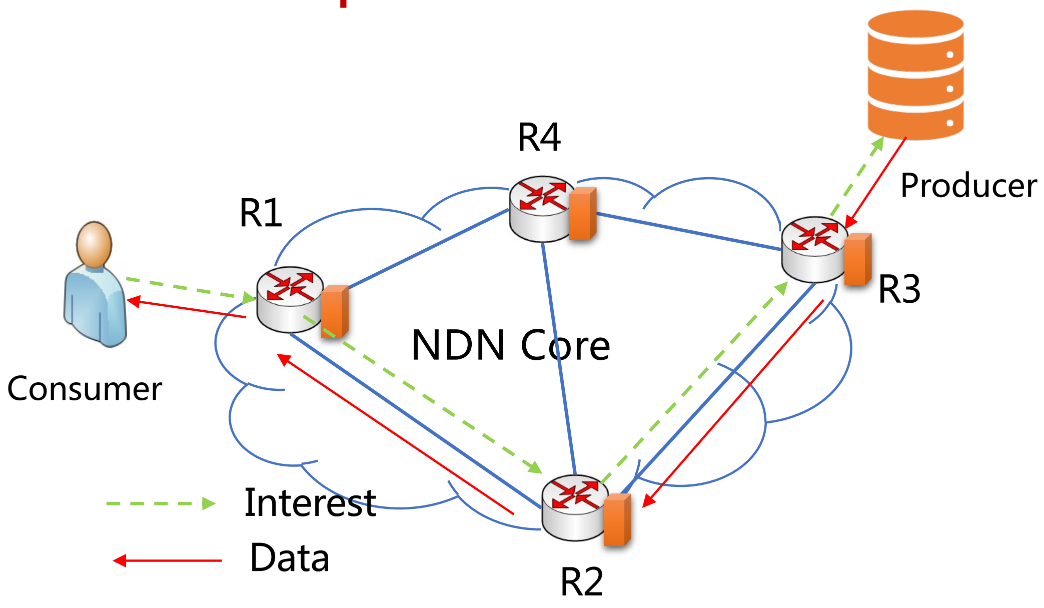
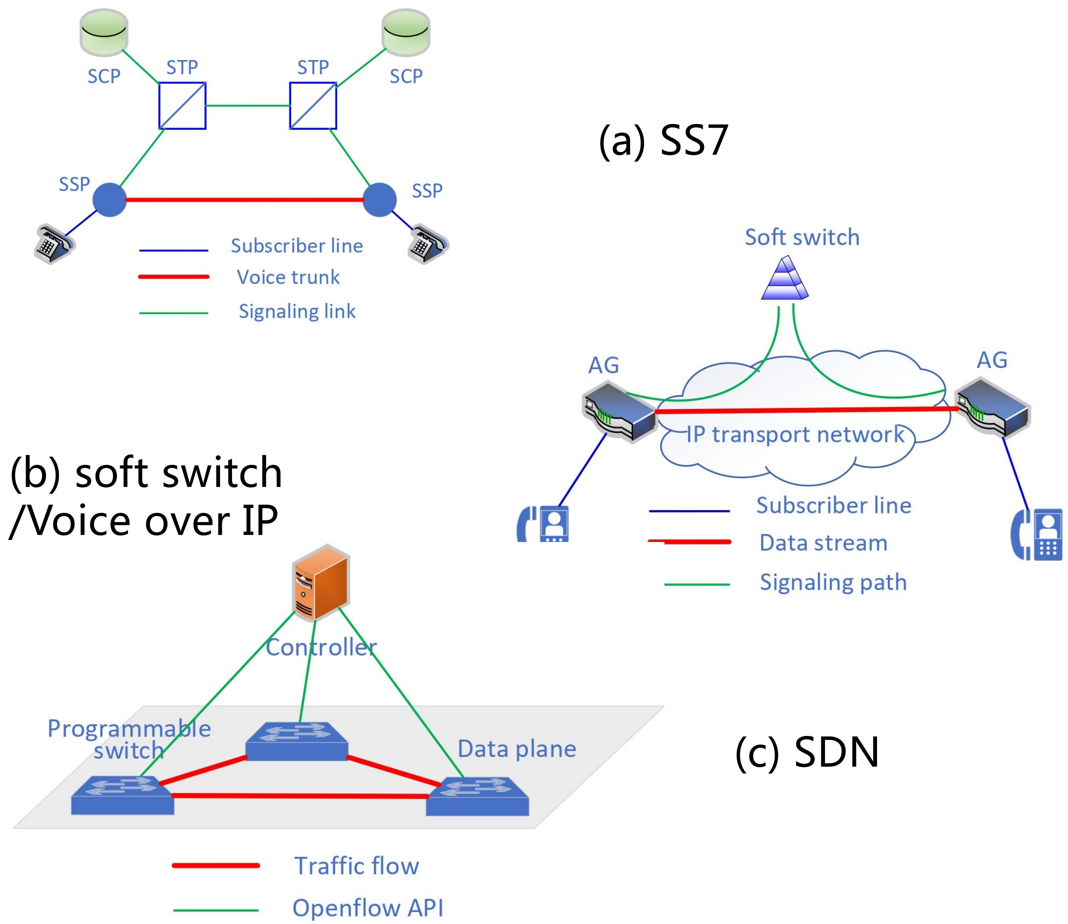
Two Issues Considered

(1) Symmetric path of Interest and Data packets



Native NDN: Data packets go on the reverse path of Interest packets.



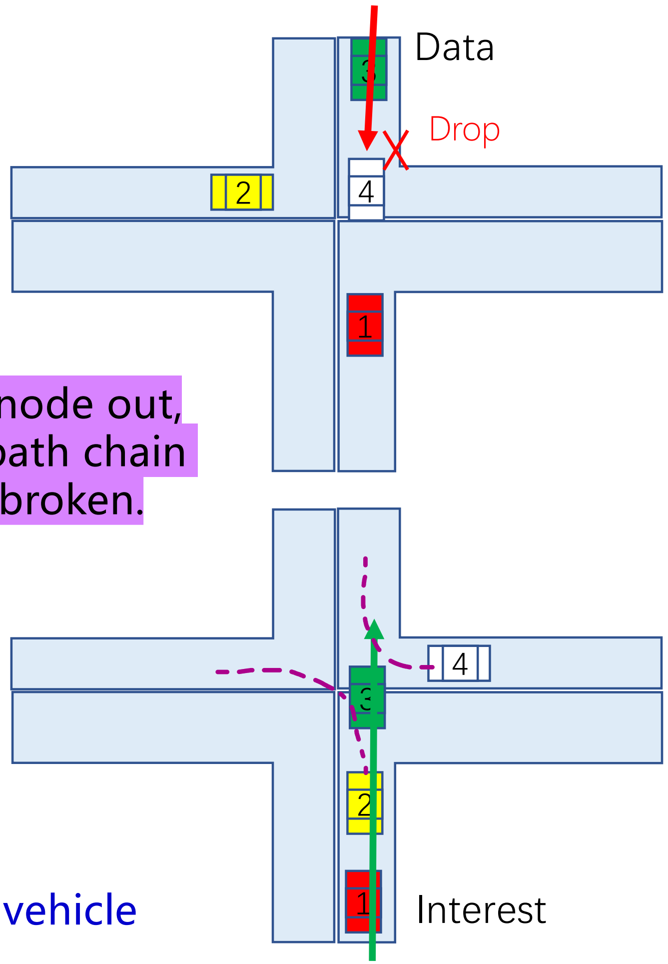
classic designs of network architecture

Disadvantage: symmetric paths

What happen if intermediate nodes disappear?

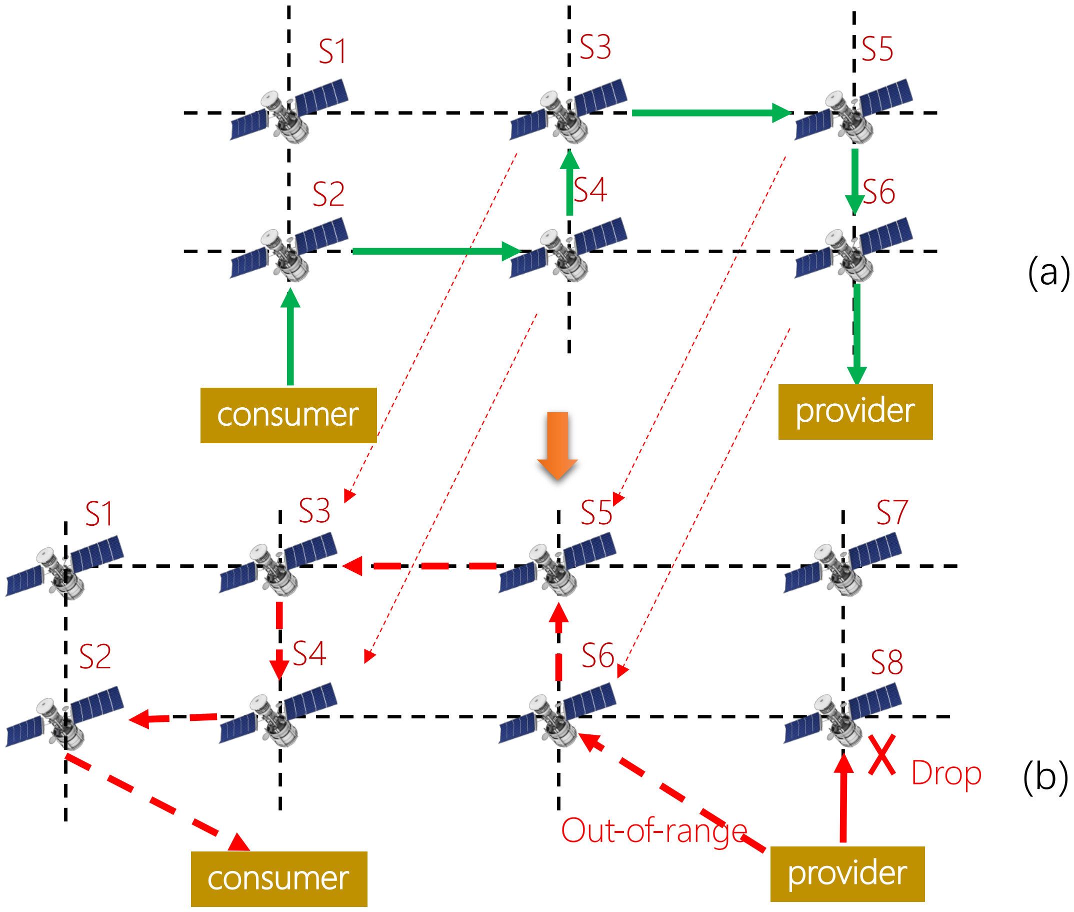
(b)

(a)



Relay node out, Data path chain easily broken.

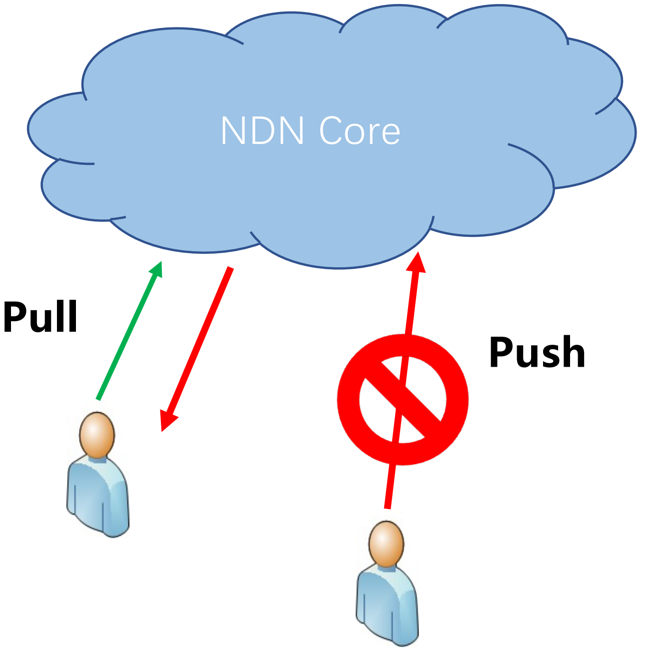
Vehicle-to-vehicle



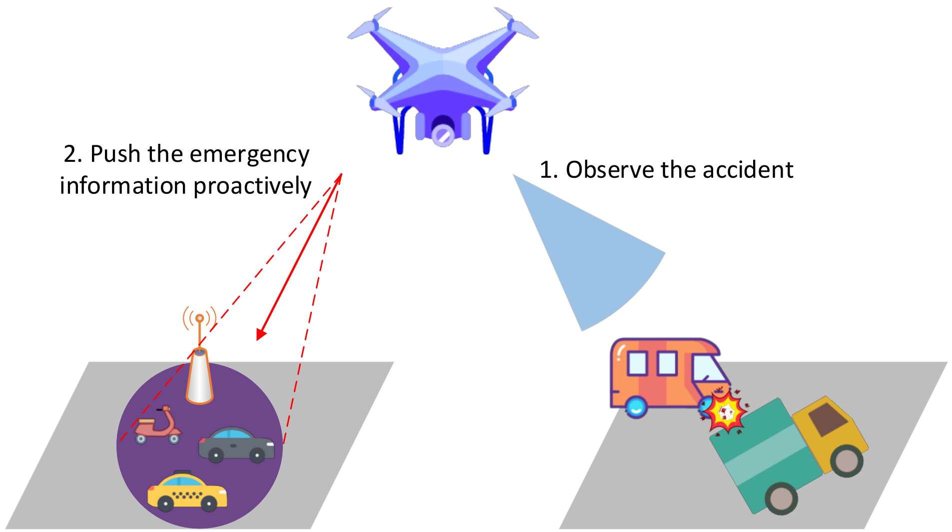
LEO satellite constellation

Two issues considered

(2) Only Pull, no Push



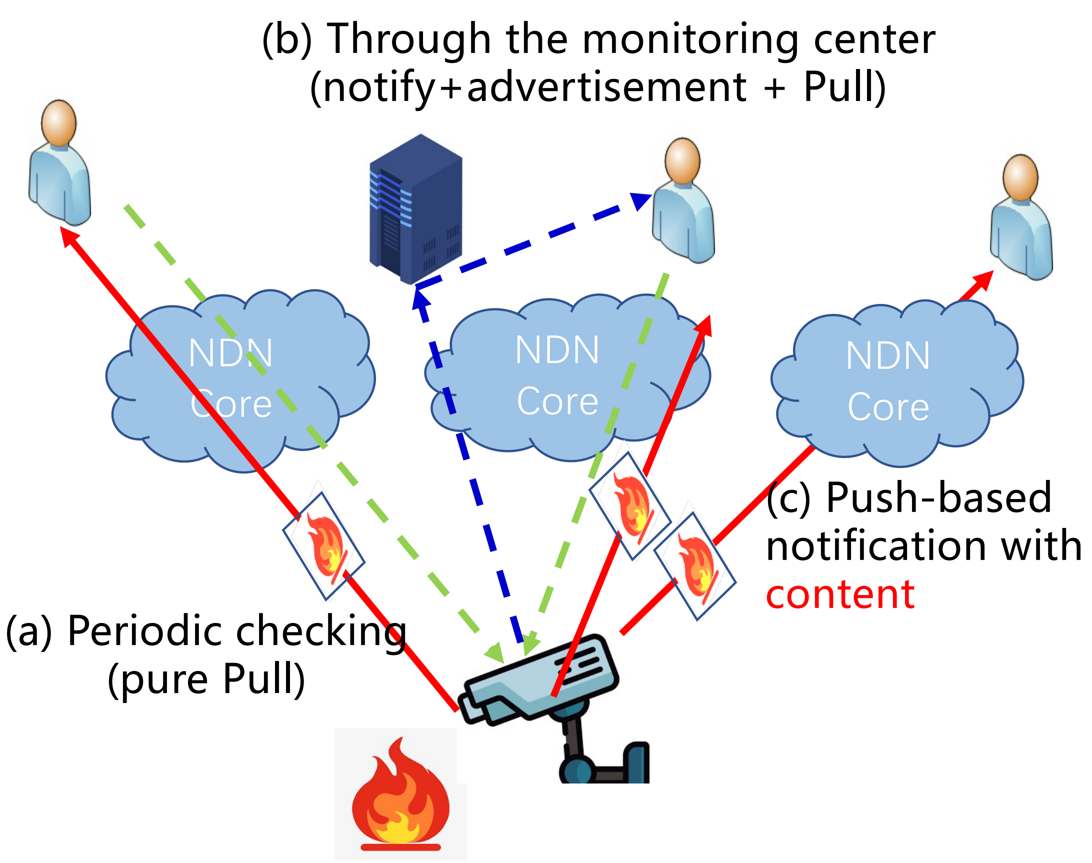
Borrow 'GET' from HTTP, ignoring 'POST'



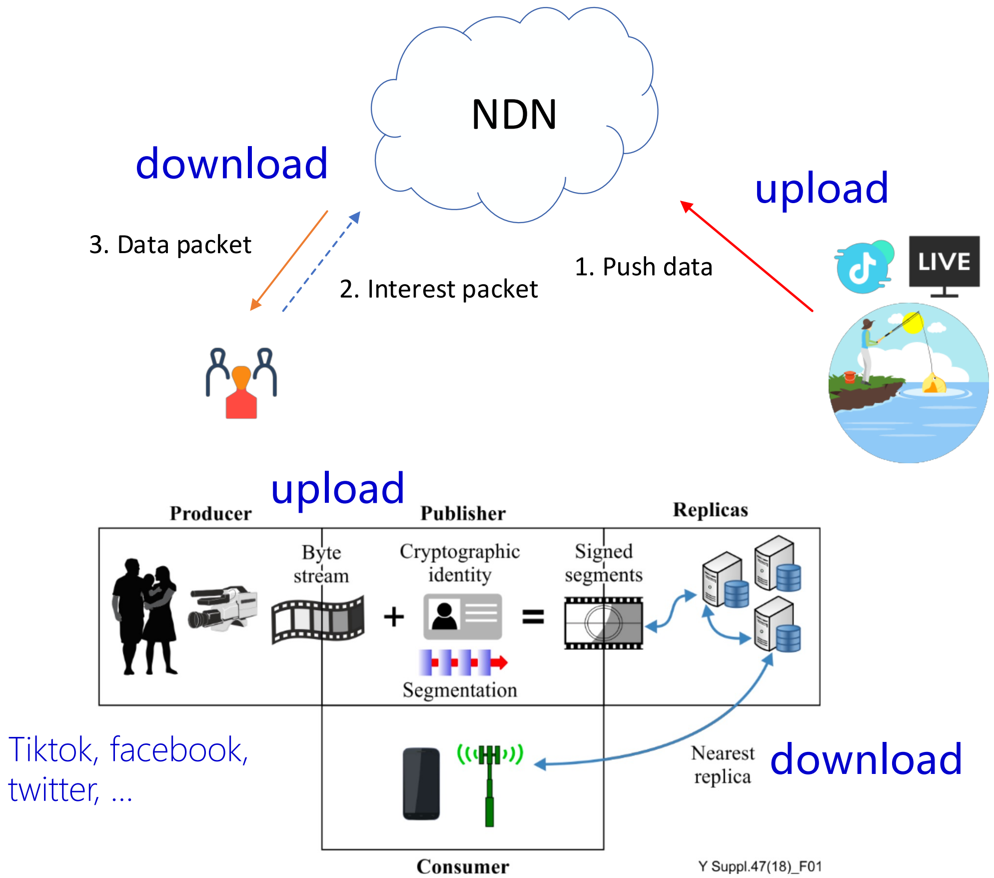
In emergency message dissemination, pull is inefficient, whereas push is more efficient.

Critical message dissemination

Disadvantage: lack PUSH mechanism



Emergence sensing

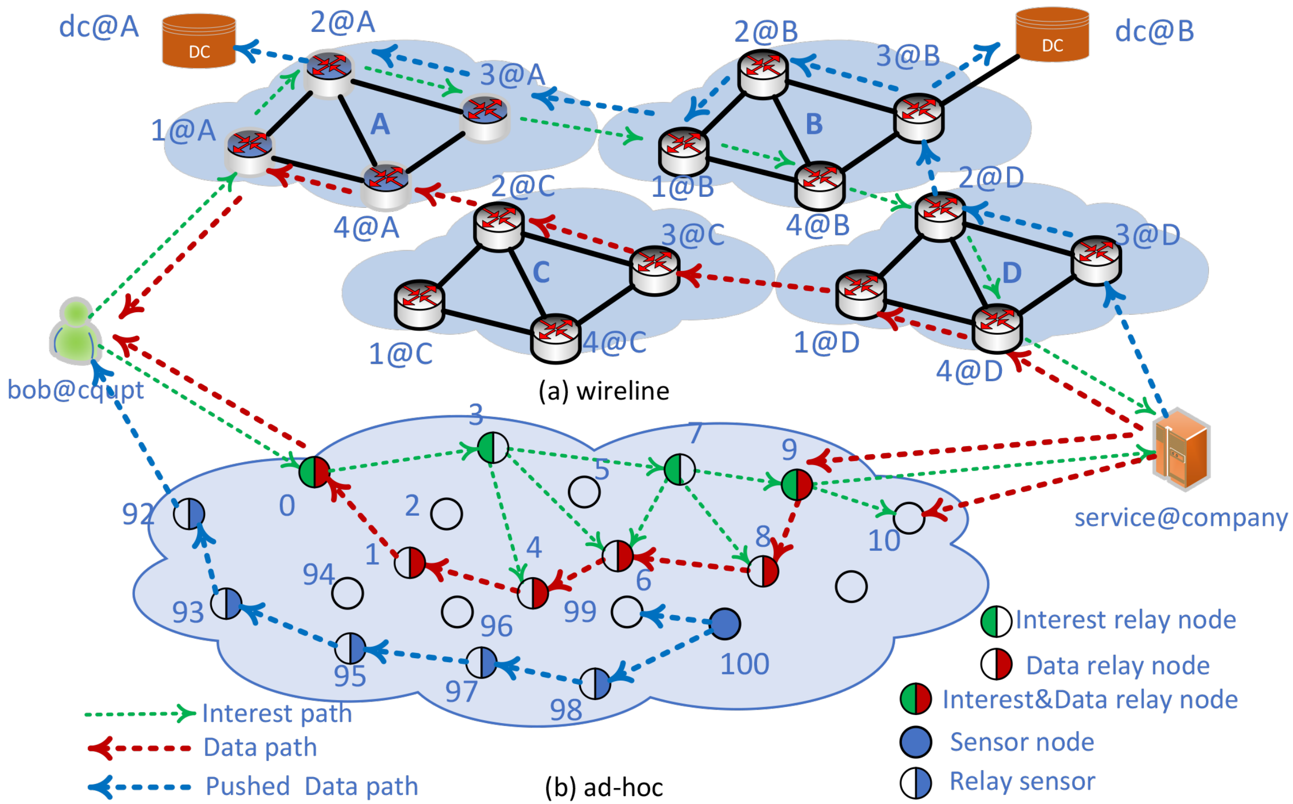


UGC sharing

UGC: user generated content

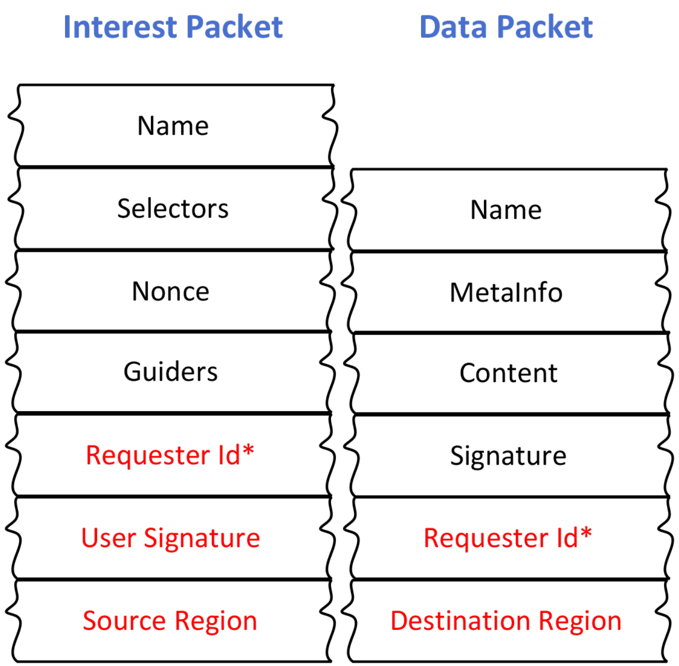
Approaches: Asymmetric NDN (aNDN)

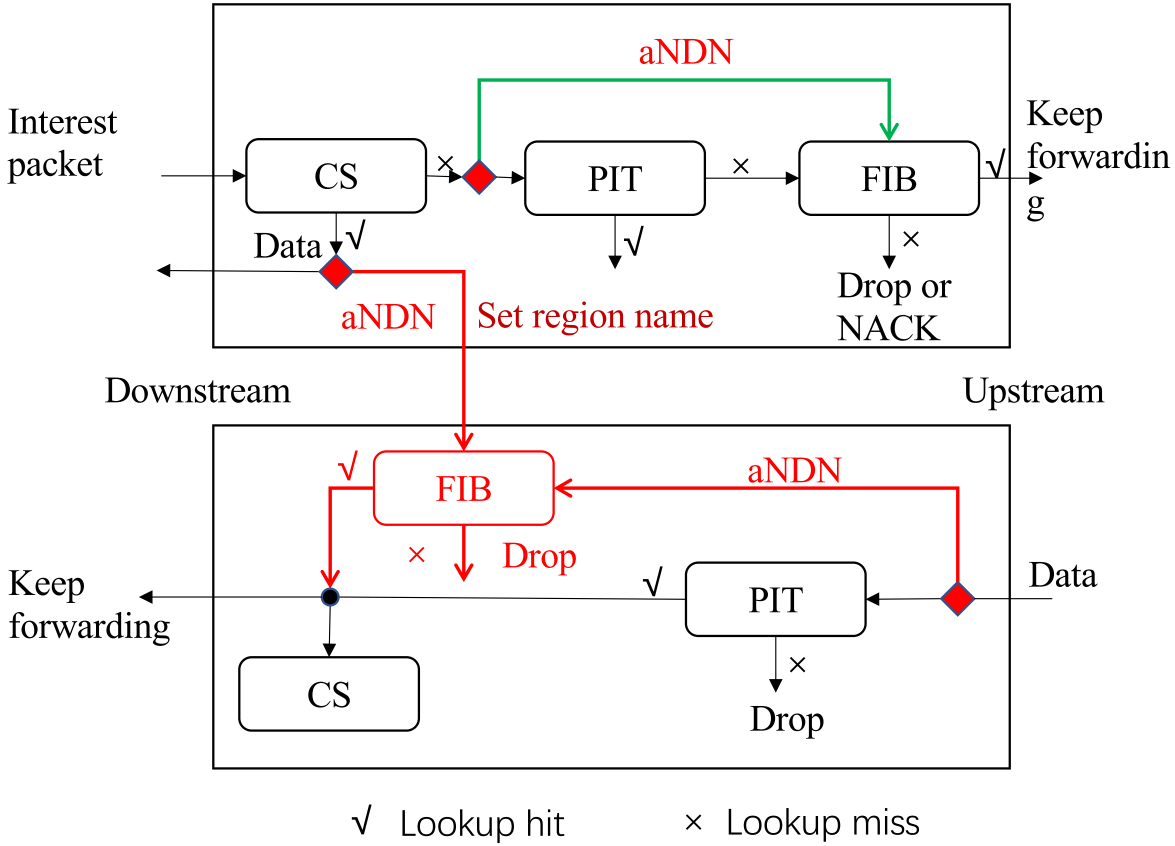
- ❑ Ideas of aNDN (initial NDN 2.0)
  - Asymmetric paths
    - Decoupling paths of Interest and Data packets
  - Supporting Pull and Push
    - Request-response
    - IoT sensing
    - Data-center updating
  - Naming everything
    - Data, consumer, producer, host, region, …
  - Optional stateful forwarding



Luo J. et al, Asymmetric framework evolution of Named Data Networking and Use Cases in VANET, HotICN 2020

aNDN -Packet and Forwarding



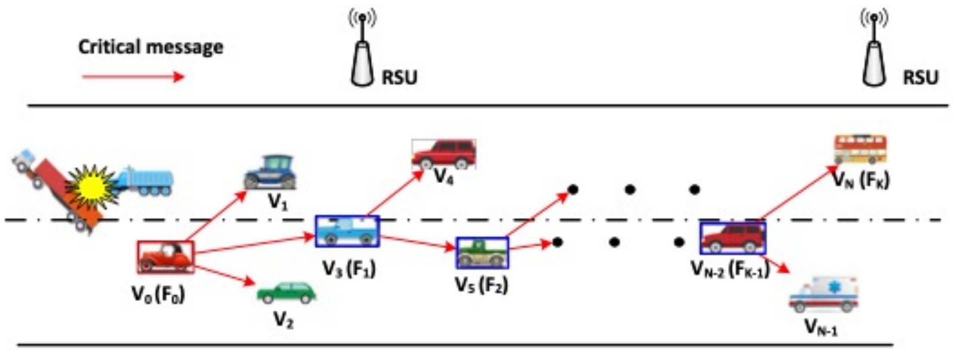


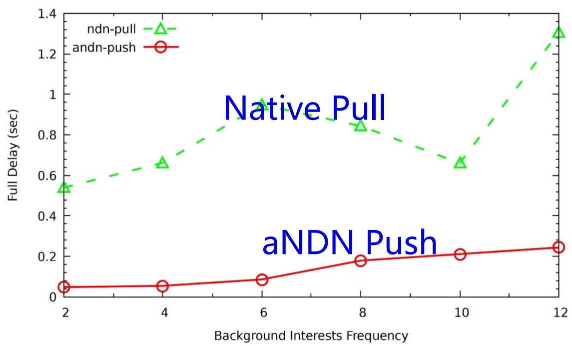
aNDN Packet format

aNDN forwarding process

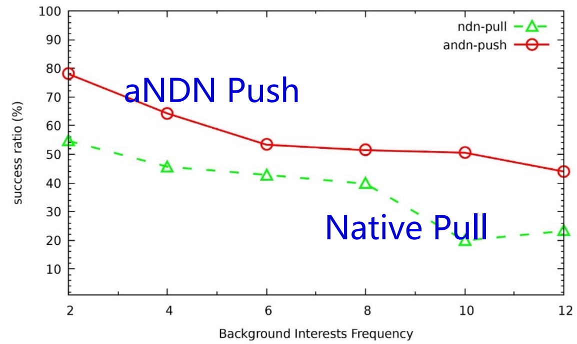
Benefits of aNDN: Push vs. Pull

- Critical message dissemination in V-NDN
  - Native NDN: Pull contents
  - aNDN: Push contents





(a) Average full delay



(b) Success ratio of Data delivery

Configurations:

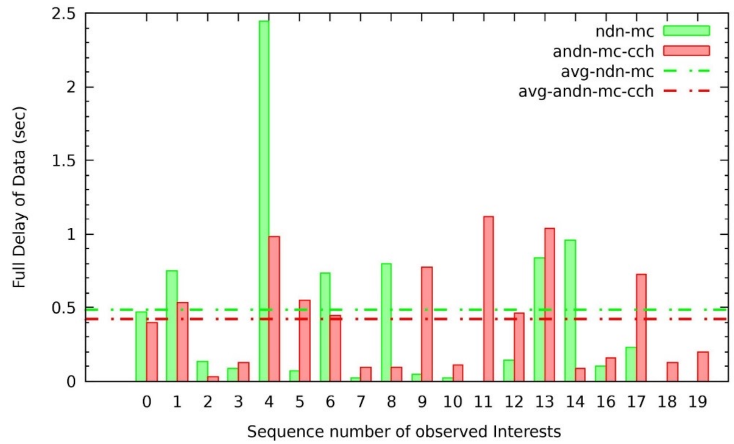
- Both multicast strategy
- Success ratio(SR): $\frac{N_{receive}}{N_{transmitted}}$, N: the number of data pkts

X axis: Background Interests Frequency (Int./sec)
Y axis: Full delay(sec)

Push outperforms pull completely: almost half latency, higher delivery success ratio, under different background load.

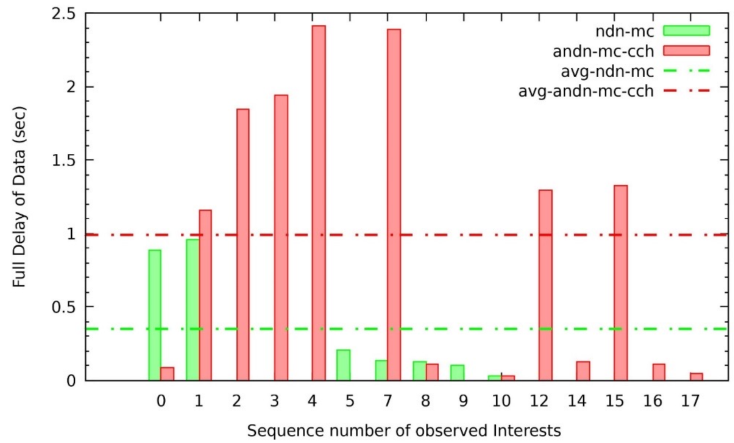
Benefits of aNDN: asymmetric vs. symmetric

- Content dissemination in V-NDN by pull
  - Native NDN: Data/Interest on WAVE SCHs; Data on reverse path of Interest
  - aNDN: Interest on WAVE CCH, Data on SCHs; independent forwarding (both multicast)



(a) background: 4 interests/second.

- Conclusions
  - Asymmetric scheme outperforms native symmetric one.
  - Pull more packets (13:7) under heavy load

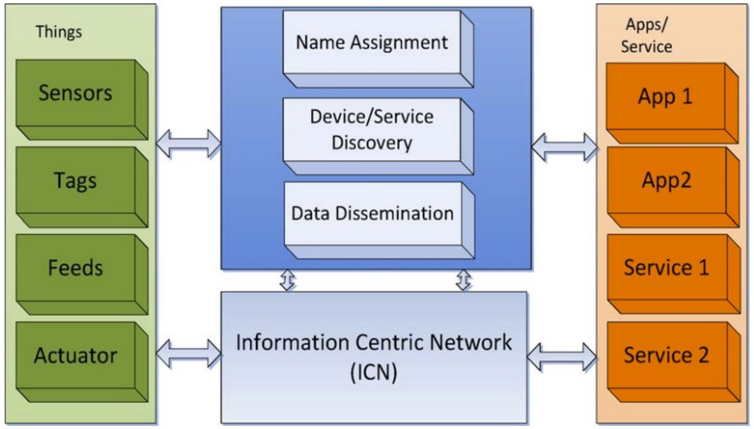


(b) background: 8 interests/second.

WAVE: Wireless Access in Vehicular Environment

(1) IoT requirements and NDN extension

- IoT requirements
  - Naming devices
    - sensors, tags, feeds, actuators, …
  - Device/Service Discovery
  - Data Dissemination
    - Sensing/collecting
    - Commanding
- Two communication modes
  - Push: mission critical, control, sensing (critical-mission)
  - Pull: sensing, query, …
- NDN not support Push naturally



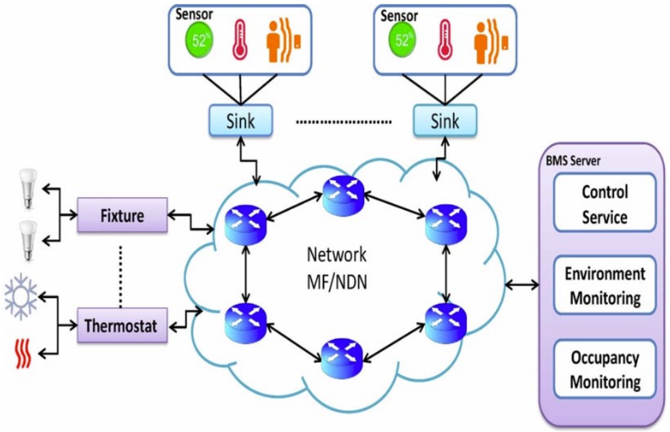
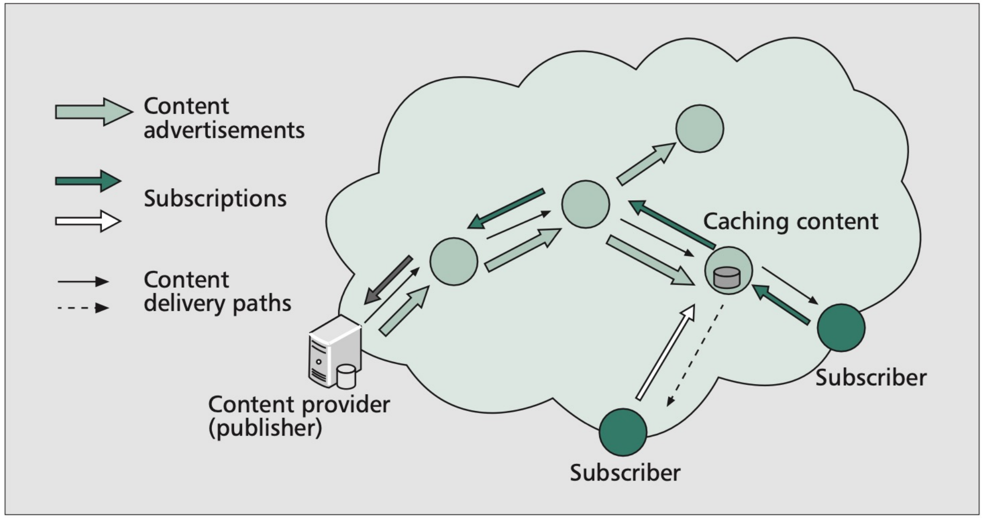
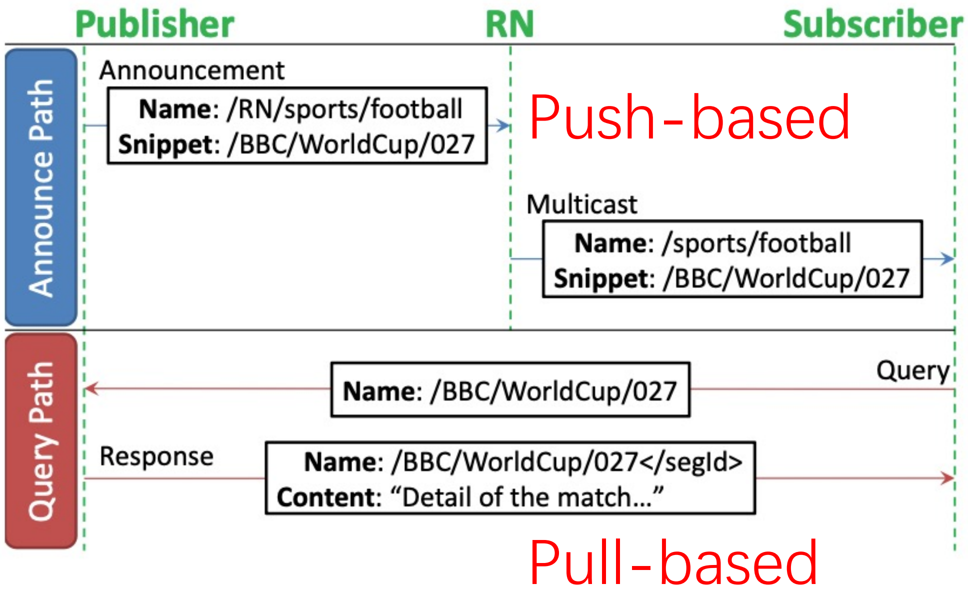


Fig. 6: BMS over MF/NDN

Suguang Li, Yanyong Zhang, et al. A comparative study of MobilityFirst and NDN based ICN-IoT architectures, 2014

(2) Social Network





Publish/Subscribe System (pull-based)

COPSS: hybrid pull-/push-based

On the advertisement from the Publisher

Being strictly, the announcement is a Push.

Snippet: small sample or preview

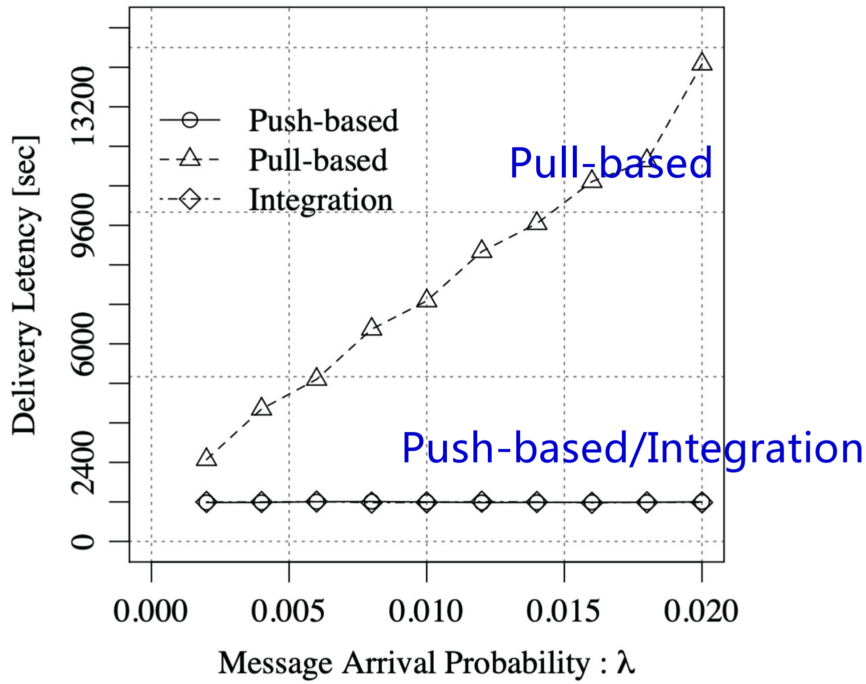
B Mathieu et al., Information-Centric Networking: A Natural Design for Social Network Applications. IEEE Comm. Mag., 2012

Jiachen Chen, ···, Xiaoming Fu, et al. COPSS: An Efficient Content Oriented Publish/Subscribe System, 2015

(3) Push/Pull in disaster recovery

❑ Disaster situation

- many people want the same information, e.g., current status, safety of family members, ...
- Networks in this area are damaged and fragmented.
- Power supply is not guaranteed, easy to interrupt



❑ Approach

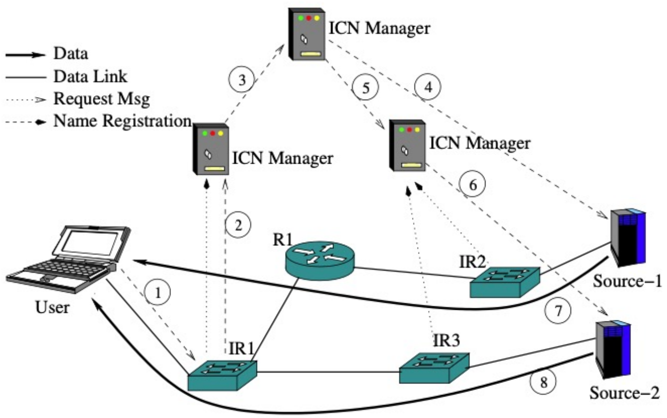
- A disaster message board
- Publish/Subscribe system integrating Push/Pull
- Data mule: ambulance, ...

Tagami, Atsushi et al. Name-based push/pull message dissemination for disaster message board, 2016 IEEE LANMAN 2016

Research Directions for Using Information-Centric Networking (ICN) in Disaster Scenarios. RFC 8884, Oct 2020

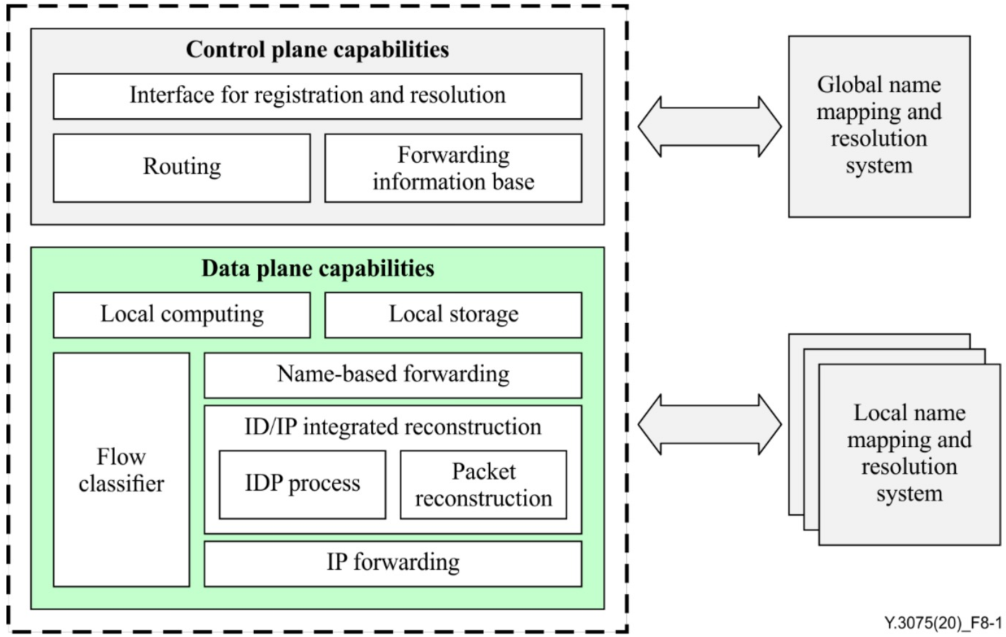
(4) Control-Data Separation

- Overlay ICN architecture (O-ICN)
  - Add an entity: ICN Manager
  - C-plane: naming, routing (decision)
  - D-plane: caching, forwarding
- Data runs different path from request messages
- Easy to implement using SDN, supporting non-SDN.



Samar Shailendra, A novel overlay architecture for Information Centric Networking, NCC 2015

- **C/D separation is required by IMT-2020 (5G)**

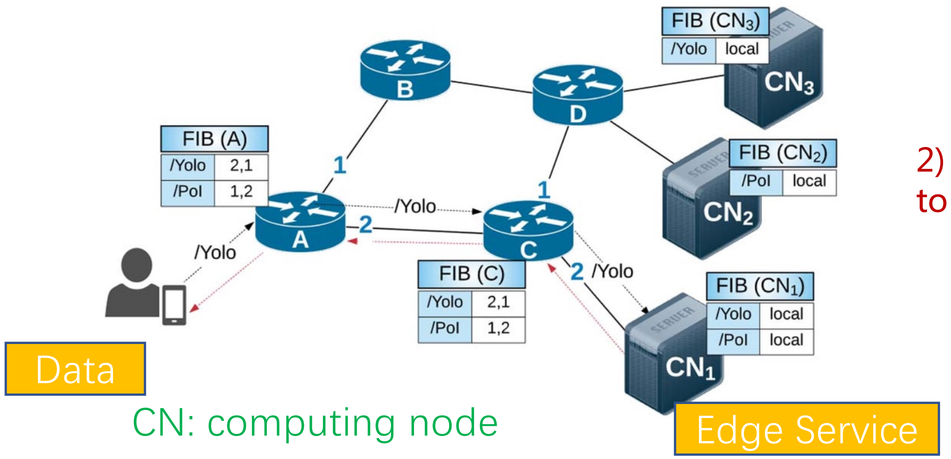


ITU-T Y.3075 (ICN-RF), Sept 2020

(5) Computing support

❑Edge computing

- Naming extension (not just Data) :
  - computing task, or AI algorithms
- ICedge:
  - Move Data to the Edge Service
  - On the service discovery path

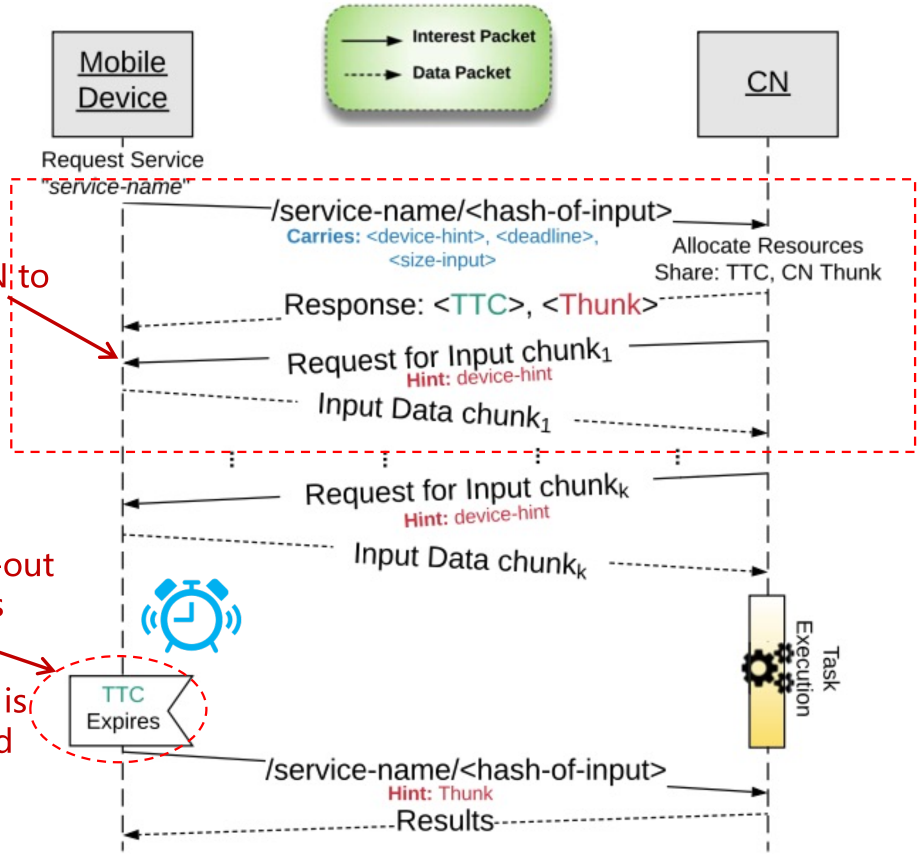


CN: computing node

1) Wait CN to Pull

2) Wait time-out to get results

The timer is estimated



Only Pull is inefficient!

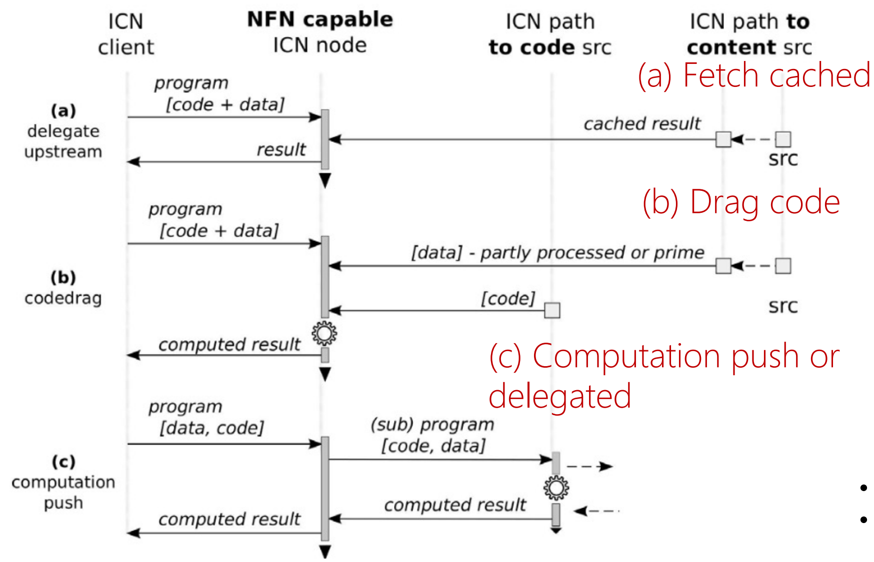
S Mastorakis, ICedge: when edge computing meets ICN, IEEE IoT Journal, 2020

(5) Computing support

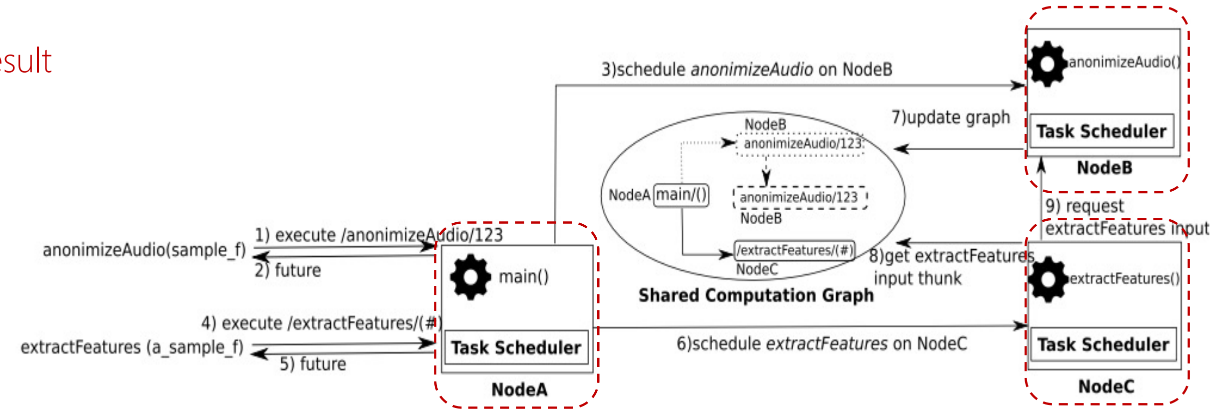
❑ In-network computing

- Named **Function** Networking (NFN) by Univ. Basel
  - ◆ Name: Data ➔ function (λ-expression)
  - ◆ Caching function, half results

- Compute First Networking (CFN)
  - ◆ Combining distributed computing framework with RICE (remote method invocation in ICN)
  - ◆ Inputs, state, outputs as named objects



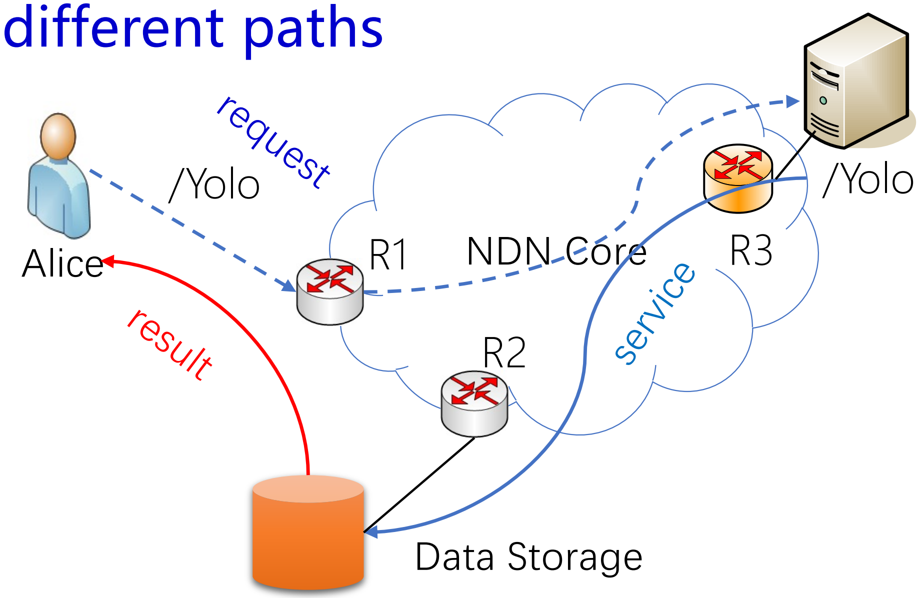
Named *Function* Networking



- C Tschudin (U Basel), et al, Named Functions and Cached Computations. IEEE CCNC 2014
- M Król (UCL), ... Dirk Kutscher, et al., Compute First Networking: Distributed Computing meets ICN, ACM ICN 2019
- M Król (UCL), ... Dirk Kutscher, et al., RICE: Remote Method Invocation in ICN, ACM ICN 2018

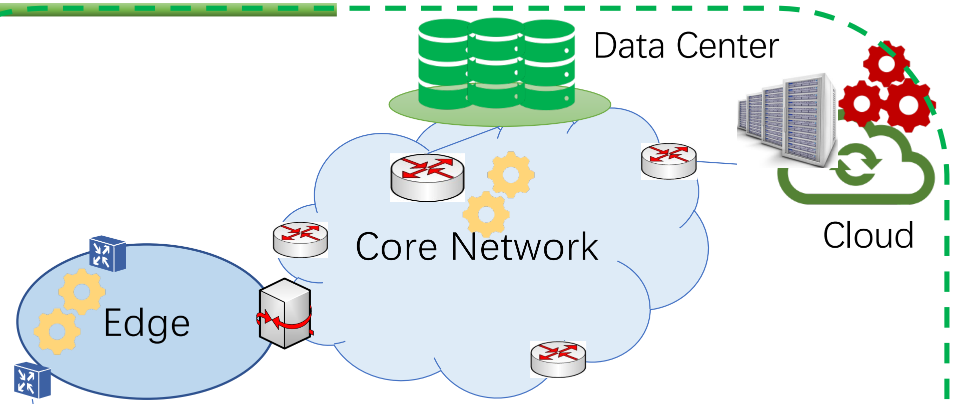
(6) Computing/Networking Integration

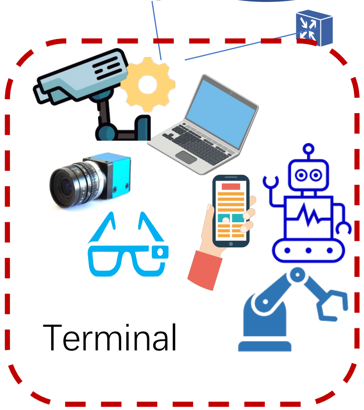
- Request, service, and Result on different paths



Alice asks for a Yolo service to detect her video files in the Data set in another place.

Service request and discovery, data storage, and computing are on different sites.

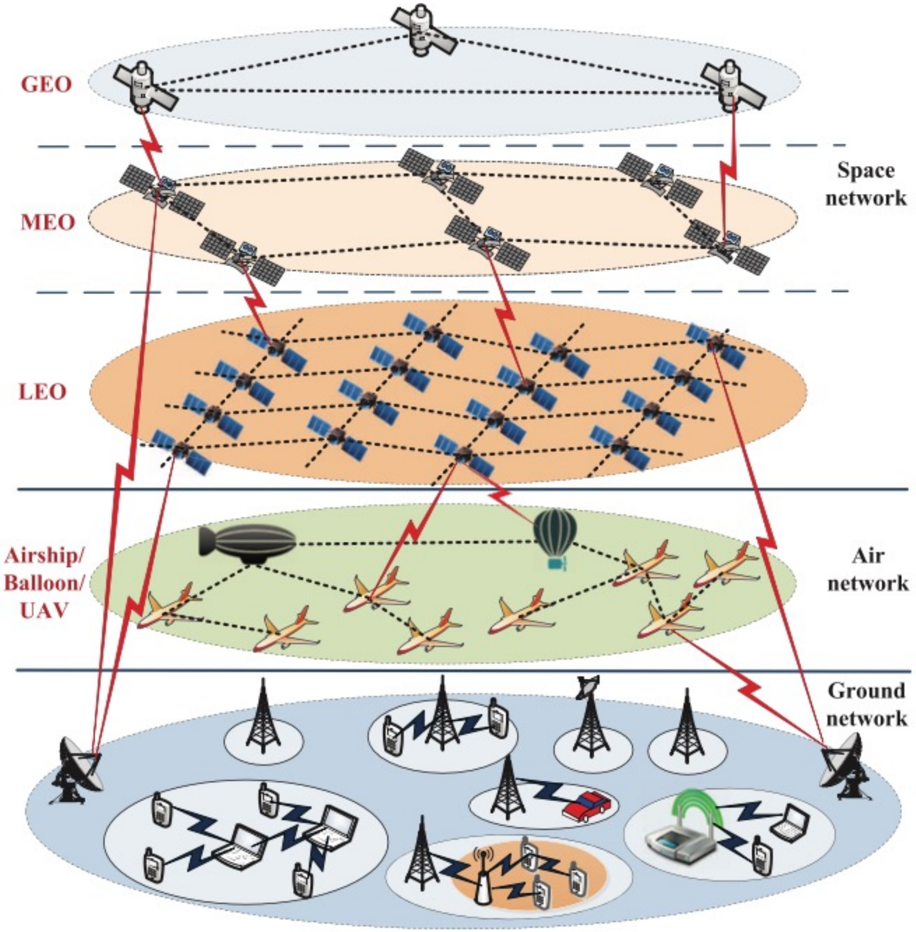




Ubiquitous intelligence in cloud, network, edge and terminals, **integration of networking, storage, computation**

NDN needs to evolve to be more flexible and compatible.

(7) Space-Air-Ground Integration (SAGIN)



J Liu et al, Space-Air-Ground Integrated Network: A Survey. IEEE Comm. Surveys & Tutorials, 2018

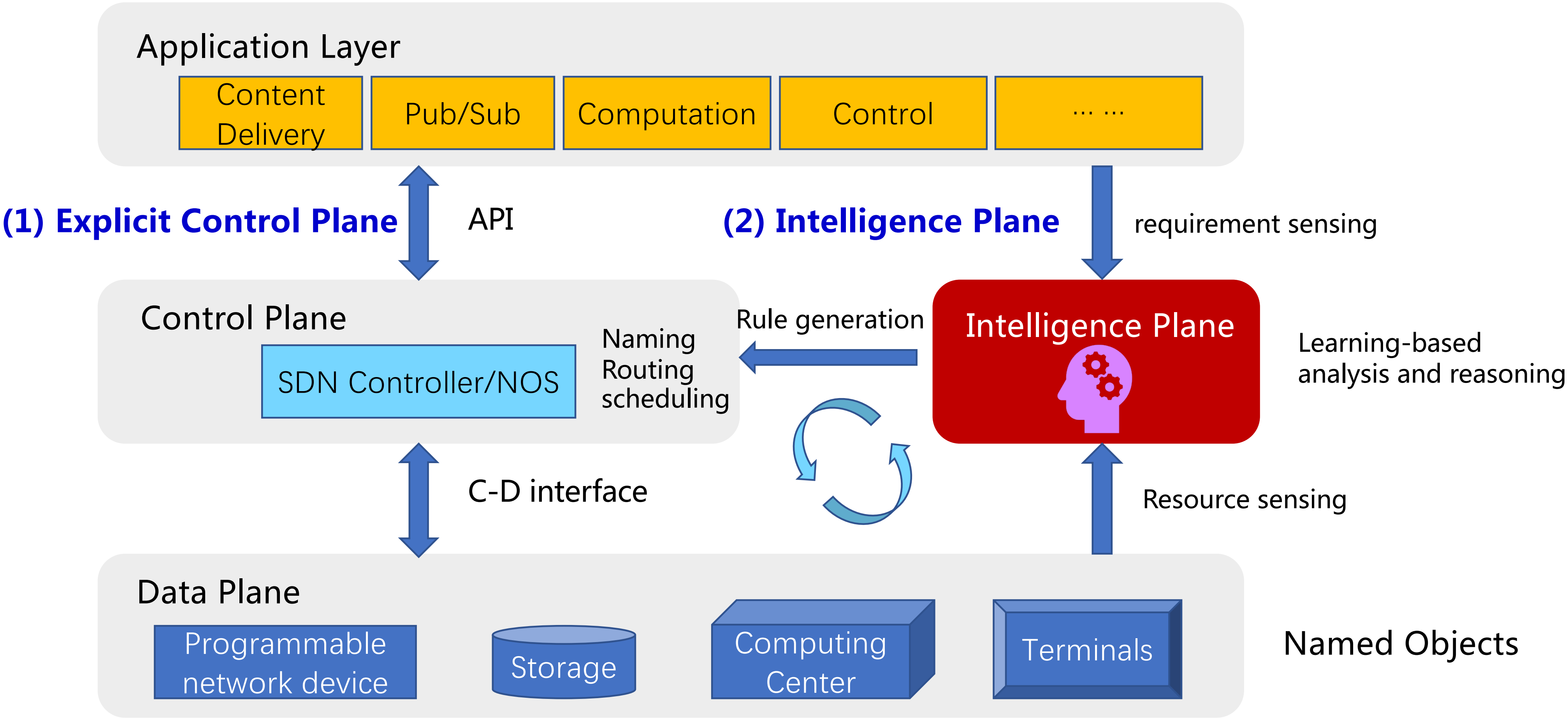
- Wealth of features, scenarios, research topics
  - Heterogenous
  - Delay/disruption tolerance
  - Intermittent links, dynamic topology
  - Consumer/content/network/producer mobility
  - Coordinated/integrated scheduling
  - intelligent forwarding
  - Edge offloading
  - Caches placement, prefetch/proactively push
  - …

As a promising architecture for the future Internet, NDN needs to evolve!

Evolution hints

item	NDN 1.0	NDN 2.0
services	content dissemination	content-dissemination (with QoS), notification, command, computation, … …
named objects	data/content	data/content, ID of service, host, user, domain, region, … …
commun. model	Pull	Pull, Push (notification, command, … …)
routing	Interest: named-based Data: reverse path of Interest (symmetric path)	symmetric; asymmetric (decoupling Data and Interest); data/storage aware; name lookup and resolution
in-network caching	caching data replica	data, code, computing result, … …
forwarding	stateful forwarding	stateful, stateless, programmable
data delivery model	connectionless	connectionless, virtual connection, deterministic,
Control plane	coupled with Data/Forwarding plane	C/D plane separation (explicit Control Plane), SDN controller, NOS
AI-enabled	N.A.	Intelligence plane

Architecture Profile



目录 Contents

Future research

- **ICN/NDN enabled 6G-oriented SAGIN**
  - Naming and resolution: not only for Data, content, information, but else devices, network entities, network domain/region, identity, even service functions, … …
  - Various mobility
  - standardization
- **ICN/NDN enabled Industrial Internet**
  - How to provide name-based connection-oriented, deterministic service?
  - Reliable commanding
  - Enable integration of sensing, networking, computing and control
- **Intelligence Plane design**
  - Model abstract; APIs for AI algorithms, distributed computing, cognitive
  - API interfacing the control plane
- **Military Applications**
  - Secure, timely, information sharing between various roles on the battle

Thanks for
Your Attention

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