School of Electrical and Computer Engineering

Named Data Networking

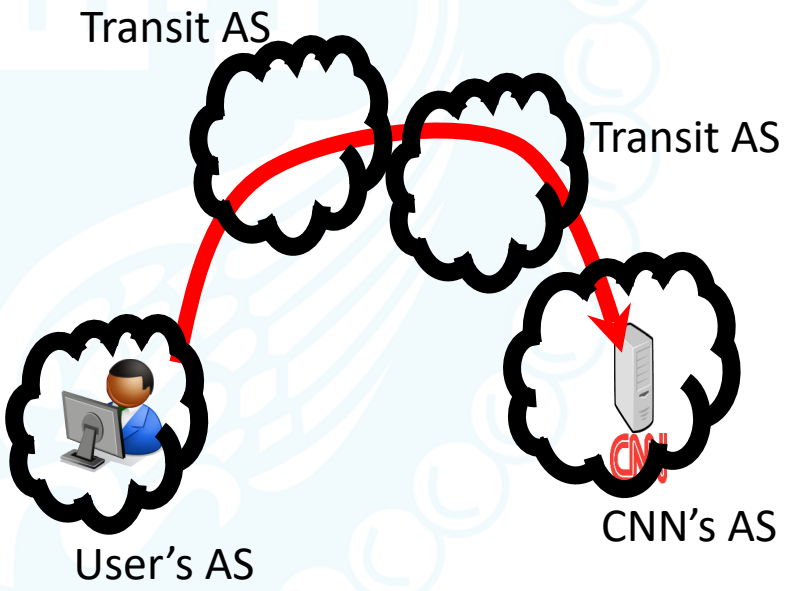
Agenda

- Current Internet Architecture
- Future Internet Architecture
- Named Data Networking(NDN)
  - Forwarding
  - Routing
  - Security
  - Privacy
  - Inter AS
  - Cache
- Routing Scalability
- Forwarding Scalability

Current Internet Architecture

- Design dates back to the **70's**
  - Inspired by **telephony systems**
  - TCP/IP

- Telephony system had two main ideas.
  - **Circuit Switching**
  - **End to End Communication**
- Main principle for TCP/IP
  - end-to-end communication



Current Internet Architecture

- Today, Internet Architecture have some Main problems:
  - **Content-intensive** communications
    - Content lookup
    - Content caching
  - **Lack of inherent Security and Privacy** solution
  - Limited to **End-to-End** connection Model
  - New Concepts
    - **Mobility**
    - **IoT**
    - **BlockChain**

The current Internet **is not efficient** anymore Also, suffers from **security challenges**

IP Routing Scalability Issues

- 2007 IAB Workshop reports:
  - The size of routing table in DFZ has been constantly growing in **super linear rate**.
  - Threatening to overwhelm the growth of hardware capabilities forecasted by **Moor's Law**
  - **Major contributing factors** to the growth of DFZ's routing tables.
    - **No Renumbering after Connectivity Change**
    - **Multihoming**
    - **Traffic Engineering**
  - So Simply, **Addressing not Following the Topology.**

Addressing vs Topology

- **Rekhter's Law**
  - Addressing can Follow Topology **or** Topology can Follow Addressing, **Choose one.**
- Global Internet topology is dictated by both technology and economic relations.
  - So, It is **infeasible to make topology follows addressing.**
- Also We see that **Addressing not Following the topology.**
- It is a **dilemma.**

Addressing vs Topology (2)

- Two types of works to address this **dilemma**
  - **Location/Identifier Seperation**
    - Provide Location-Independent Identifiers.
    - A mapping system is needed
    - So allow IP address allocation, re-organized to follow the topology.
  - **Separate Provider and Customer address space**
    - Assigning Customer networks, unique identifier
    - Mapping those identifiers to the connected provider networks.
    - Removing the need for renumbering when customer changes providers and facilitating multi-homing
- **Differences**
  - Location/ID separation impose major architectural change without strong incentives.
  - Address space separation, matches the natural need for evolution.
- **Similarities**
  - Both attempts to control the routing table size by **mapping non-routable names to routable names**

Addressing vs Topology (3)

- So **a main design choice**:
  - Which identifier is announced into the routing plane and how to provide the reachability to non-globally-routable identifiers.

Estimation ?

- 2019
  - Routers with large routing table on BGP have **7x10^5 address routes**
  - The number of websites on the internet this year was **1.6x10^9.**
  - Total Number web pages provided by websites is **5.48x10^9.**
  - **Assuming the amount of content is 1.5-2x the number of web pages → 10^10 contents**
  - This means that when compared to BGP Routing, **10^5** more than the BGP routing table on DFZ routers.

Future Internet Architecture - Steps

1. **Innovations** in various aspects of the Internet
2. **Collaborative projects** putting multiple innovations into an overall networking architecture
3. **Testbeds** For real-scale experimentation

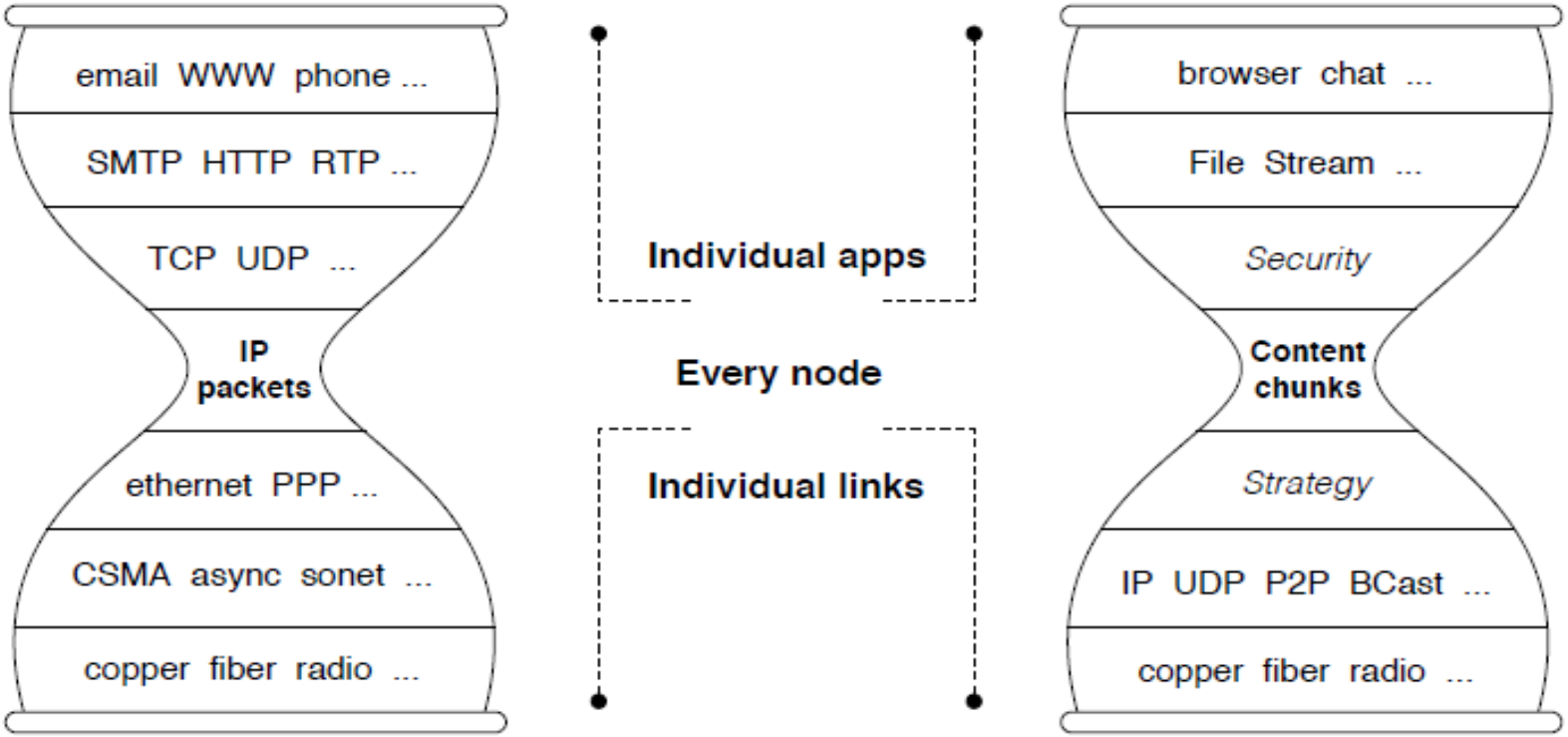
- **It may takes a few rounds to fit to all requirements**

- **NDN has mature community to do these rounds**
- **In the ICN community, the consensus is on NDN**

Future Internet Architecture – Key Research Topic

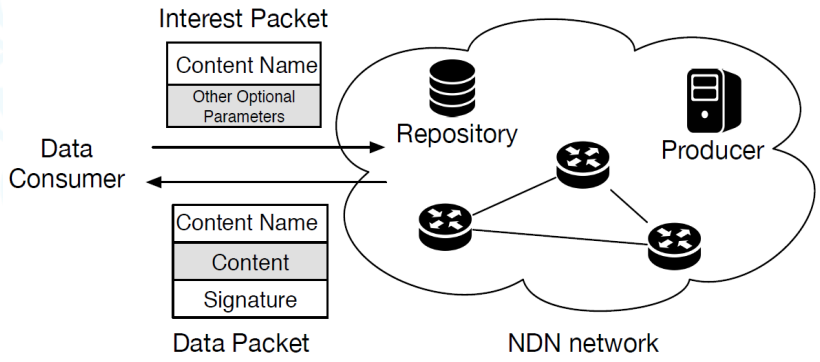
1. **Content- or Data-oriented Paradigms**
   - It is Desirable to change the architecture's **narrow waist** from IP to the data or content distribution.
2. **Mobility and ubiquitous access to the networks**
   - Mobility as the norm instead of exception
3. **Cloud Computing Centric Architecture**

Future Internet Architecture – Content Centric Networking



Named Data Networking(NDN)

- NDN is an instance of Information-Centric Networking(ICN)
- Funded by NSF as a Future Network Architecture.
- Changing network data shipping mechanism from host-centric to data-centric



- Requesting packet (*Interest Packet*) just carry a name for requested data
- NDN network processes the interest packet and then forwards it to the data producer
- Each Data producer names the data and sign it at production time

NCNU-CSIE / videos / badminton / 1(version) / 2(segment)

Routed Name　Application　Application instance

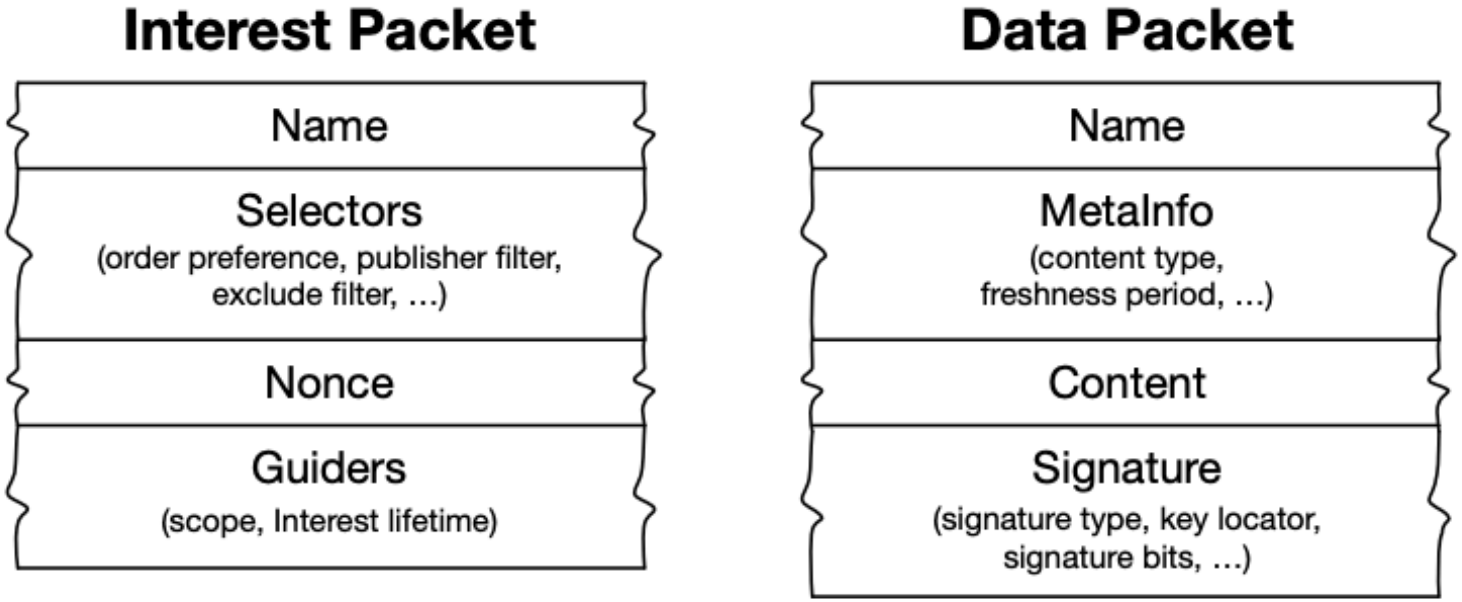
Named Data Networking(NDN)

- **IP Network**
  - Each endpoint uses IP addresses to reach the destination they desired
  - 172.23.1.16 (IPv4) , 2001:0db8:85a3:0000:0000:8a2e:0370:7334 (IPv6)
- **NDN Network**
  - Each data consumer just send an hierarchy unique name
  - Each name is completely unique
  - Each data has its own name and its own signature which implies it built-in security option of NDN network
  - NCNU-CSIE / videos / badminton / 1(version) / 2(segment)

Routed Name — Application — Application instance

Data packets carries neither an address nor any information about the requester

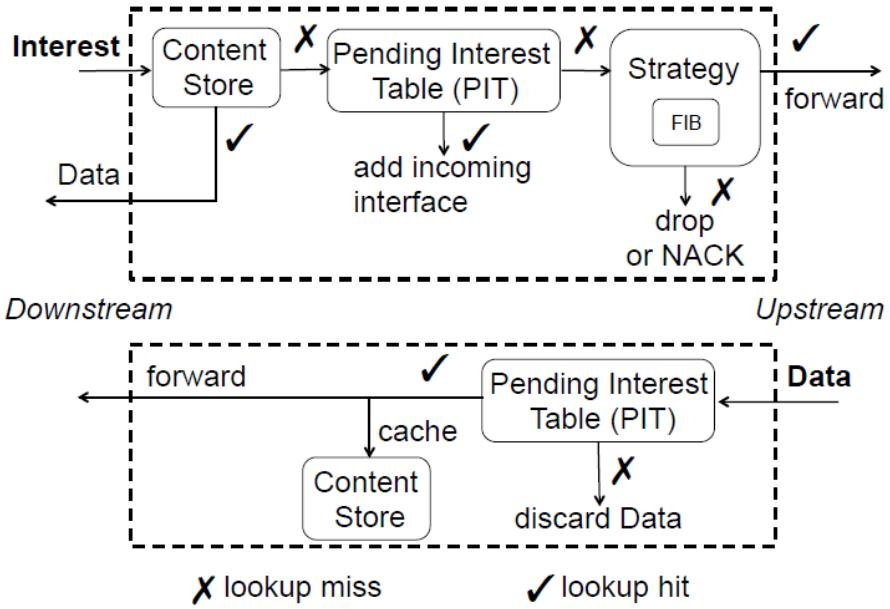
Named Data Networking(NDN)



Named Data Networking(NDN)

- Each NDN router has **three data structure** and **a module** to forward interest and data packet.

1. **CS** *(Content Store)*
2. **PIT** *(Pending Interest Table)*
3. **FIB** *(Forwarding Information Base)*
4. **Forwarding Strategy Module**



- **Content Store**
  - If the requested data exist in CS then send it back to the requester
  - Else if the data is retrieved from data producer, it can be cached in CS to serve future request based on caching policy

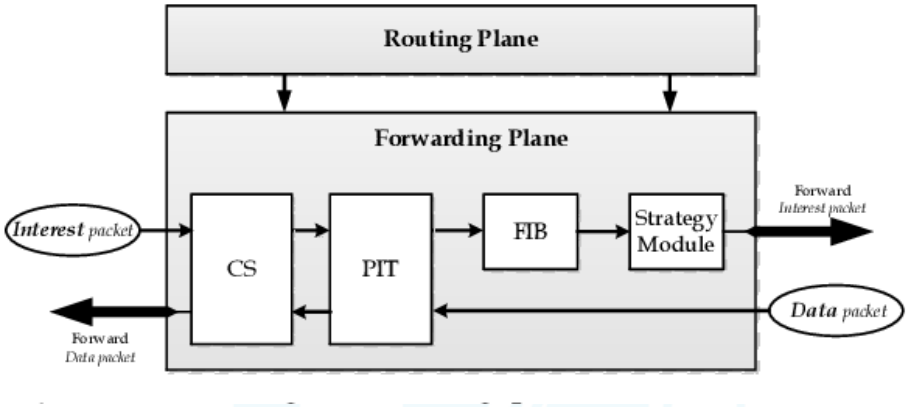
Named Data Networking(NDN)

- **Two core questions in design of network architecture.**
  - Naming
    - The **Identitiy** that each packet carries.
    - Provides **identification** between packets.
  - Forwarding
    - Forwarding packets based on the **identity**
    - Concerns the **reachability**
- **Answers in TCP/IP**
  - Naming: Source and Destination address
  - Forwarding:
    - Routers run routing protocols to setup FIB.
    - Forwarding is **Stateless**
- **Most significant difference between IP and NDN.**
  - Naming **Endpoints** vs Naming **Data.**
  - **Stateless** Forwarding Plane **vs** **Statefull** Forwarding Plane

Named Data Networking(NDN) - Routing

- **Guides each "Interest Packet"** to all potential providers (all paths).

- **Any routing algorithm** that works for IP (e.g. OSPF, Link State) can used in NDN.



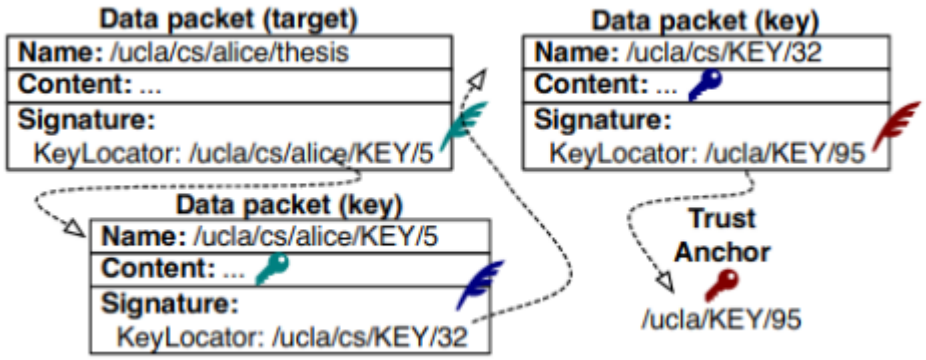
- Differences:
  - Replace IP prefix with **name prefix**
  - Calculate a **list of next hops** of each name prefix.
  - Propagate routing updates using interest/data packets.

Named Data Networking(NDN) - Routing

- **NLSR Routing Protocol**
  - Use **link state** routing algorithm.
  - **NDN Native**
    - Name, not addresses
    - Interest/Data are used to distribute
  - ***Multipath Support***
    - Modified Dijkstra's algorithm to produce a ranked list of next-hops
  - **Security**
    - Routing data is signed by originating router.

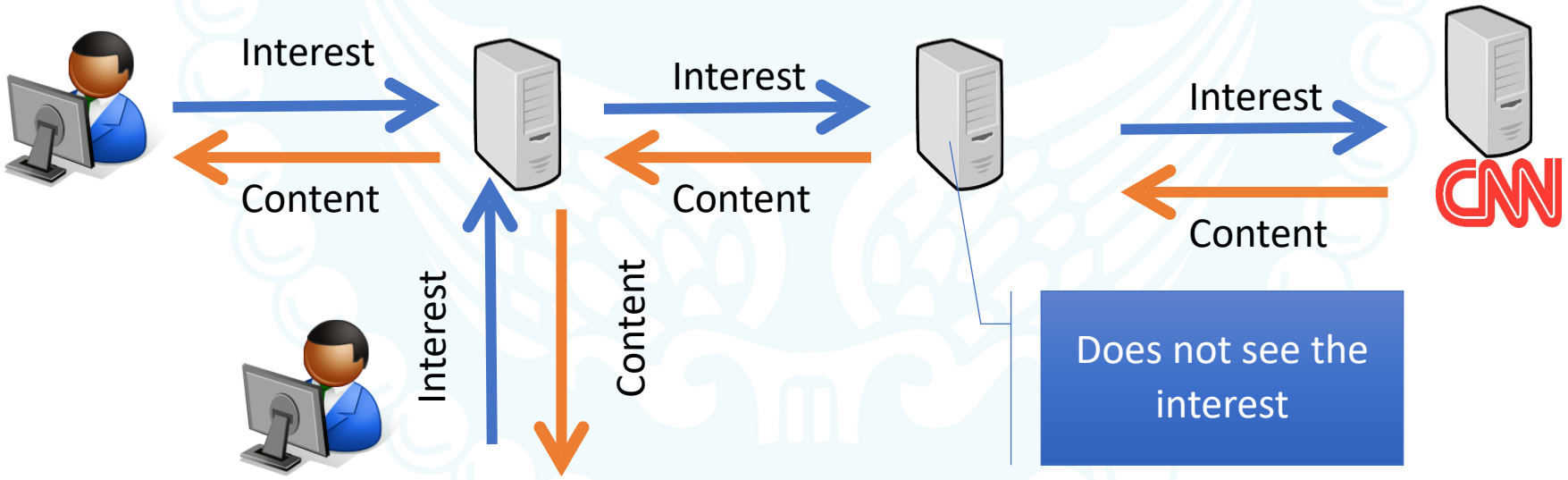
Named Data Networking(NDN) - Security

- All content objects are **signed** by the publishers
  - Authenticity
  - Integrity
- Content objects are **encrypted**
  - Confidentiality of content

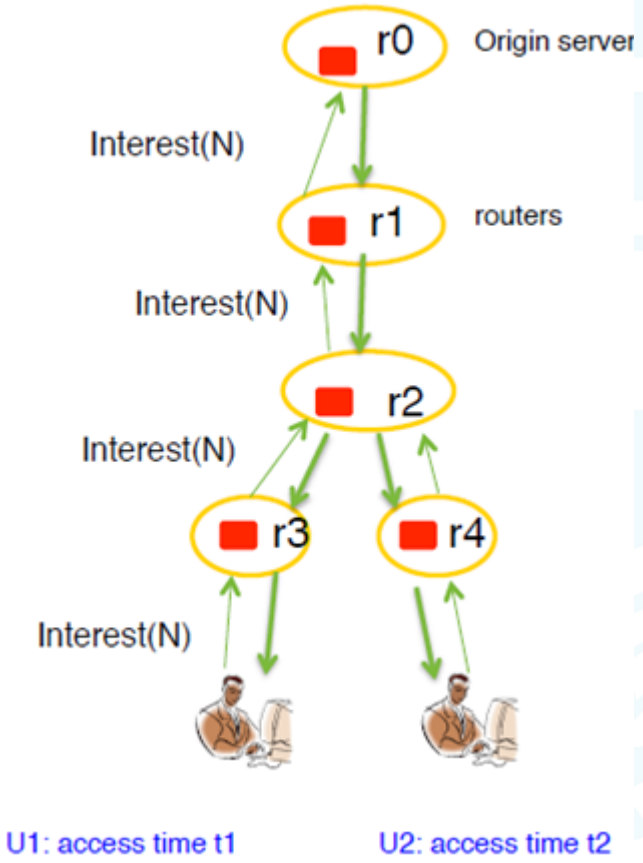


Named Data Networking(NDN) - Privacy

- No “source address” in content interests
  - Not needed for routing
- Traffic monitoring less effective for non-global adversaries



Named Data Networking(NDN) - Privacy

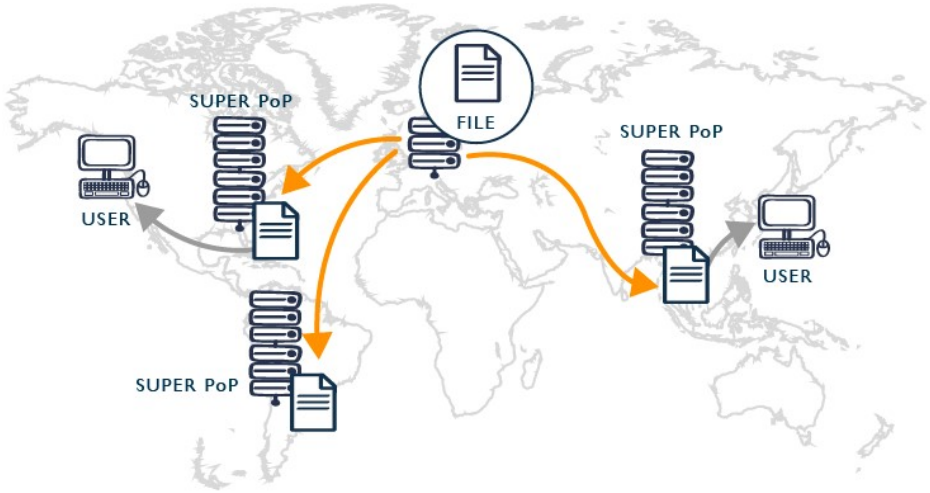


NDN Advantages

- Not Limited to End-to-End Connections
- Self Learning in small Networks
- Fast Recovery
- In-Network Cache
- No Need to Additional Network Layer Addressing
- Inherent Security
- Delay Tolerance Network
- Multi Interface Forwarding
- Automatic Security Key Management
- Utilizing Current Network Solutions
- We can define Forwarding Strategies

Caching in CDN

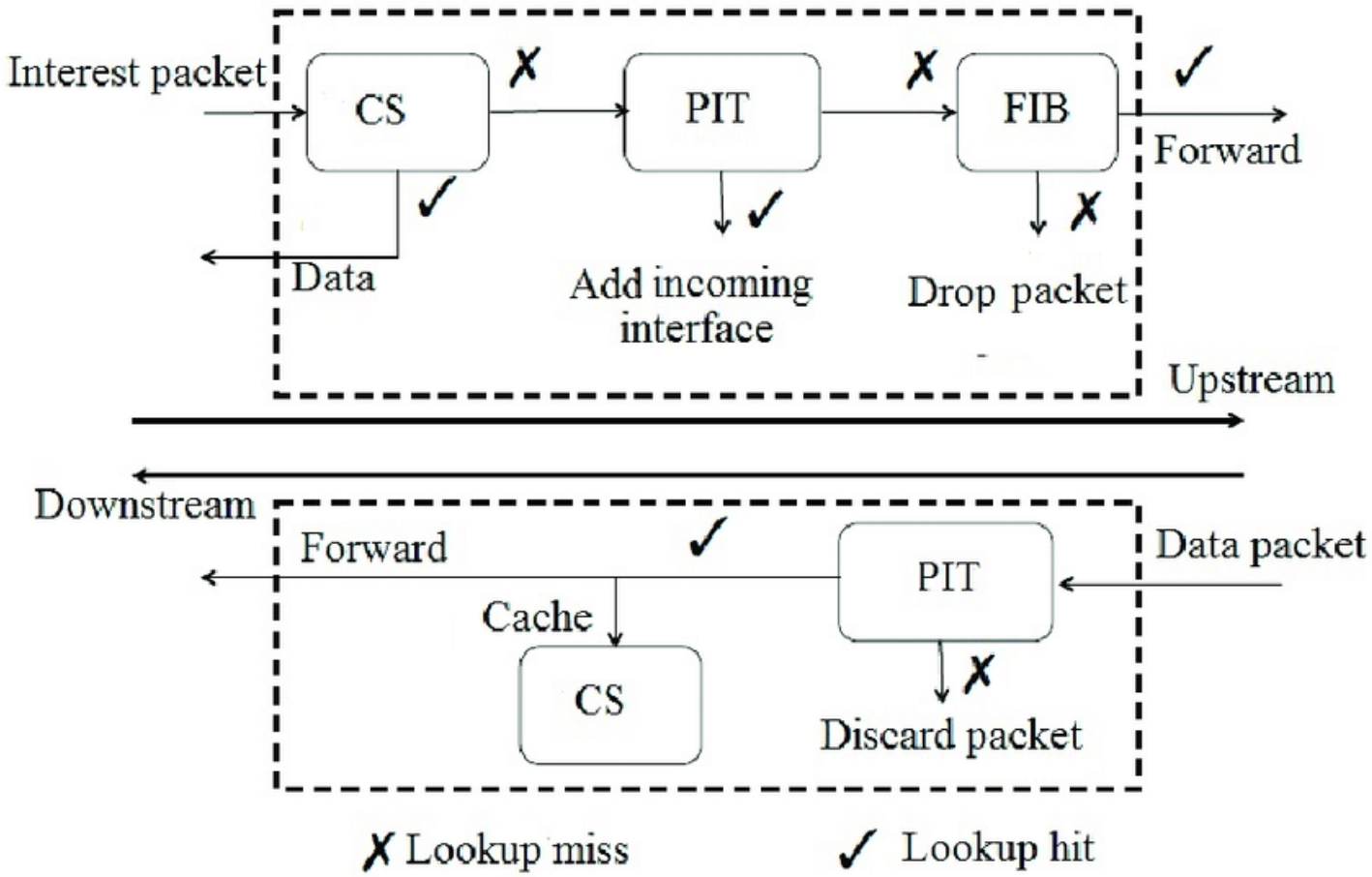
- A content delivery network (CDN) refers to a geographically distributed group of servers which work together to provide fast delivery of Internet content



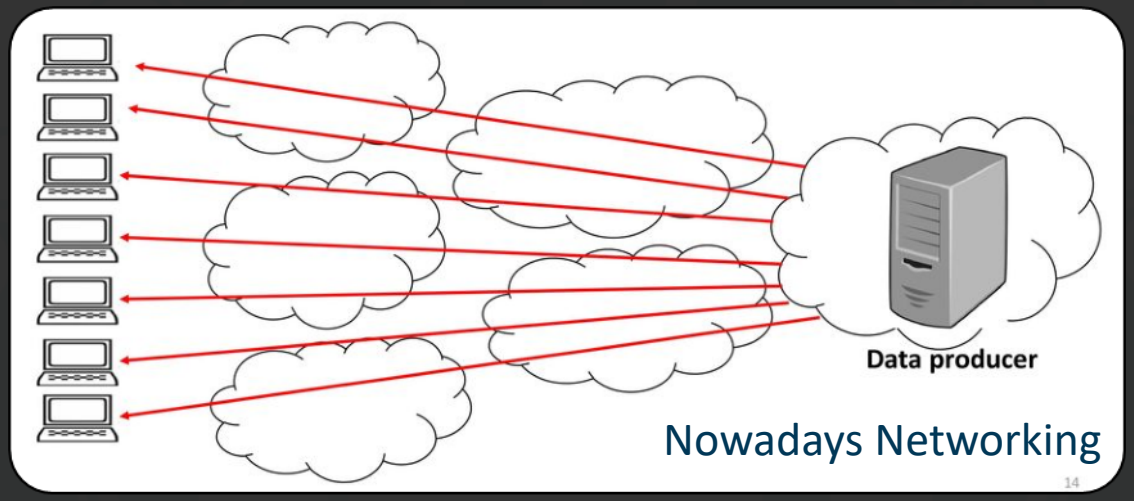
- CDN does not host content; in contrast, it does help cache content at the network edge, which improves website performance.

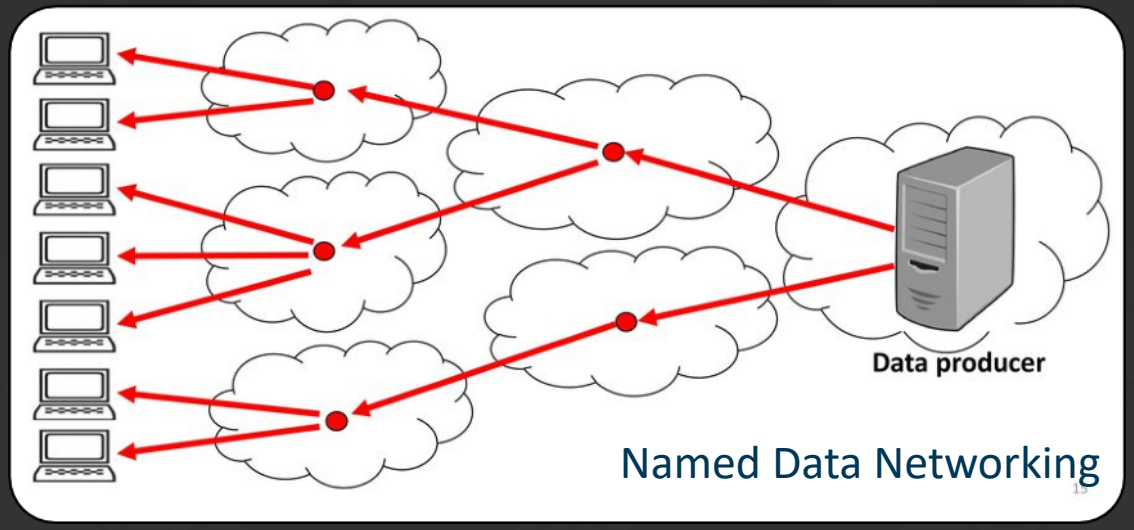
CDN aims to cache data in the nearest server to users

In-Network Cache



Nowadays Networking vs. NDN



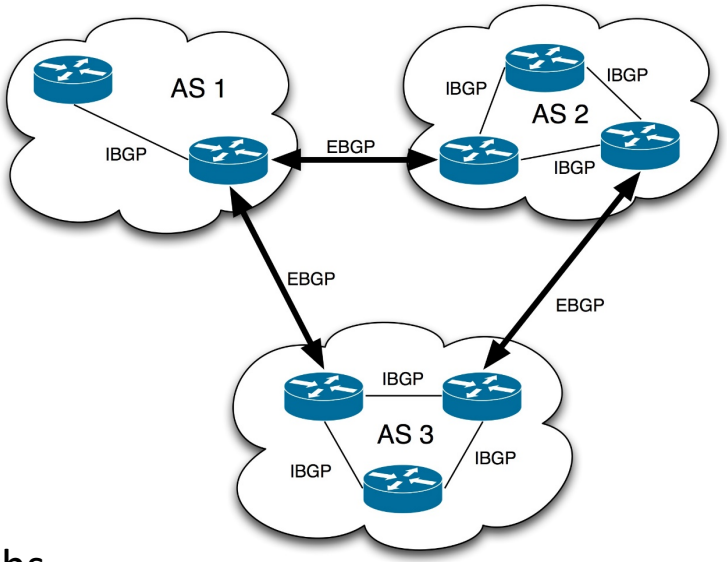


Classic NDN Cache Solutions

Leave Copy Everywhere	Replicates the content at every node it passes through on the path from source to requester.	Maximizes content availability and hit ratio.
Leave Copy Probability	Replicates the content at a node based on a certain probability.	Balances between redundancy and availability.
Leave Copy Down	Replicates the content only at the node directly before the requester.	Reduces cache redundancy closer to requesters.
Move Copy Down	Moves the cached content closer to the edge of the network when accessed.	Improves response times for future requests.
Randomly Copy One	Randomly selects one node to store the content upon a request.	Simple and does not require complex algorithms.
Probabilistic Cache	Caches content in selected nodes based on the probability to optimize cache space and improve hit ratio.	Enhances cache utilization and reduces network traffic.

Policy Routing and Border Gateway Protocol(BGP)

Routing protocol used between ASes

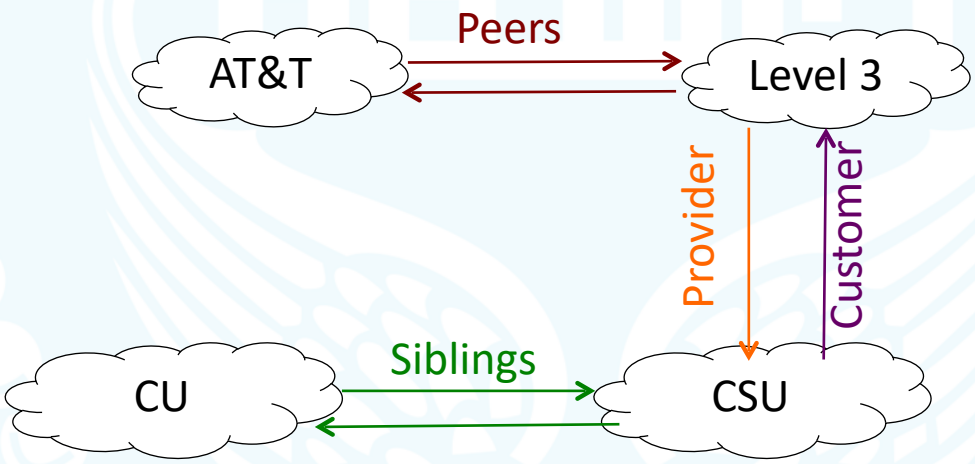


Routing Policy

- To steer traffic through preferred paths
- Inbound/Outbound prefix filtering
- To enforce Customer-ISP agreements

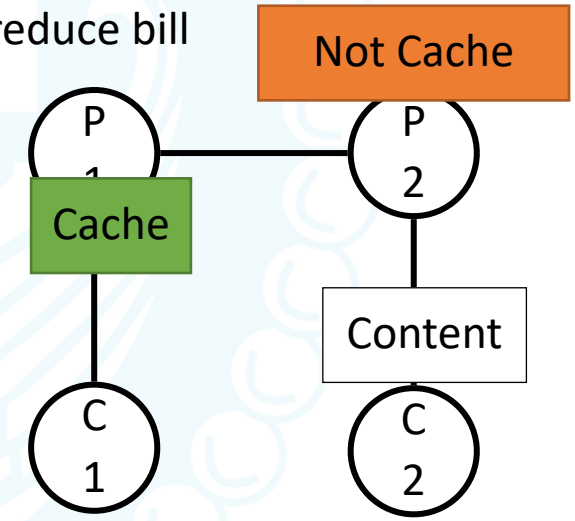
Named Data Networking(NDN) – Inter AS Routing

- Inter-domain routing is **policy-based**
- ICNs may lead to new & interesting policies
- Policies are defined by **economic incentives**



Named Data Networking(NDN) – Inter AS Routing

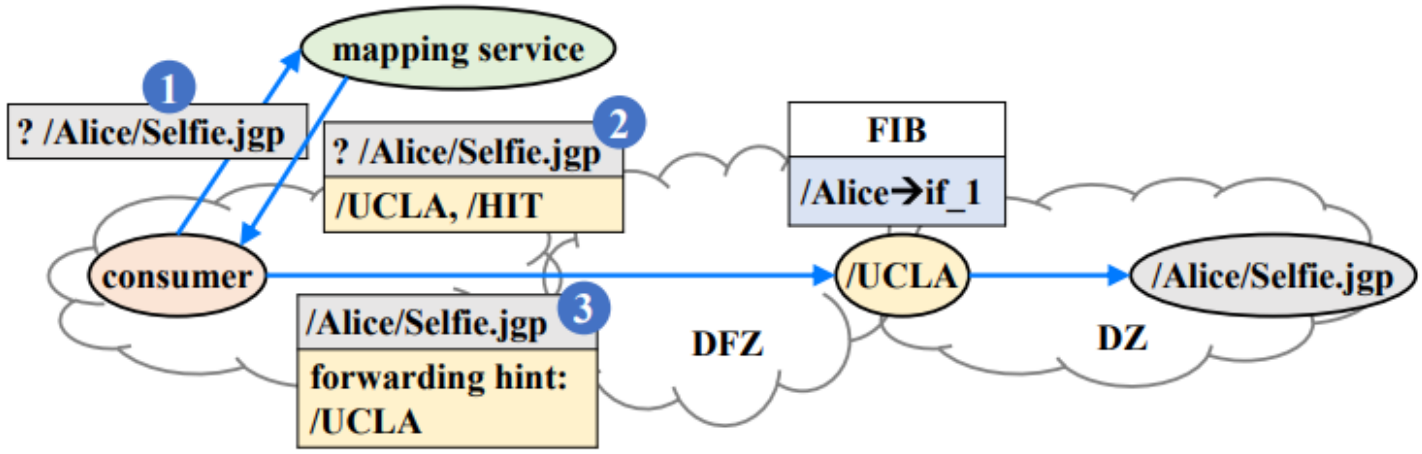
- Policies driven by **economic incentives**
- **Multi-Path Incentives:**
  - Using multiple paths = paying multiple times
  - Need to choose between cost & robustness
- **Routing Rebates**
  - Customers may offer cached content to provider to reduce bill
- **Cache Sharing Peers**
  - Peers may have incentive to share their cache.
- **Caching Incentives**
  - Little incentive for (some) providers to cache



Routing Scalability – Solutions

a) Mapping Based Solutions

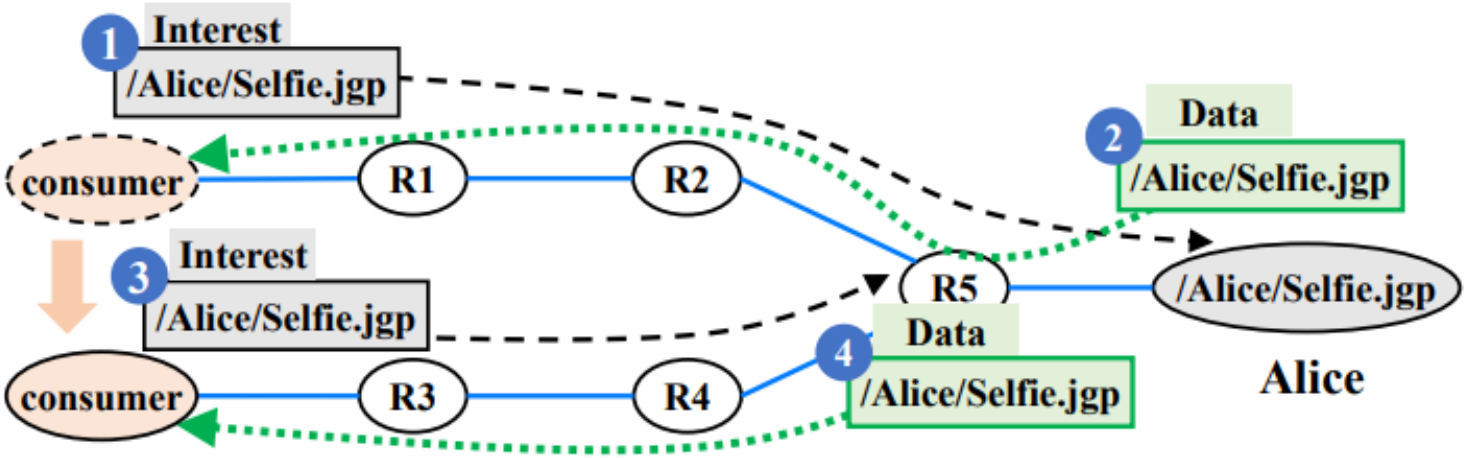
- SNAMP
  - Interests can carry both “what” (data name) and “where” (forwarding hint)



Routing Scalability – Solutions

b) Tracing-Based Solutions

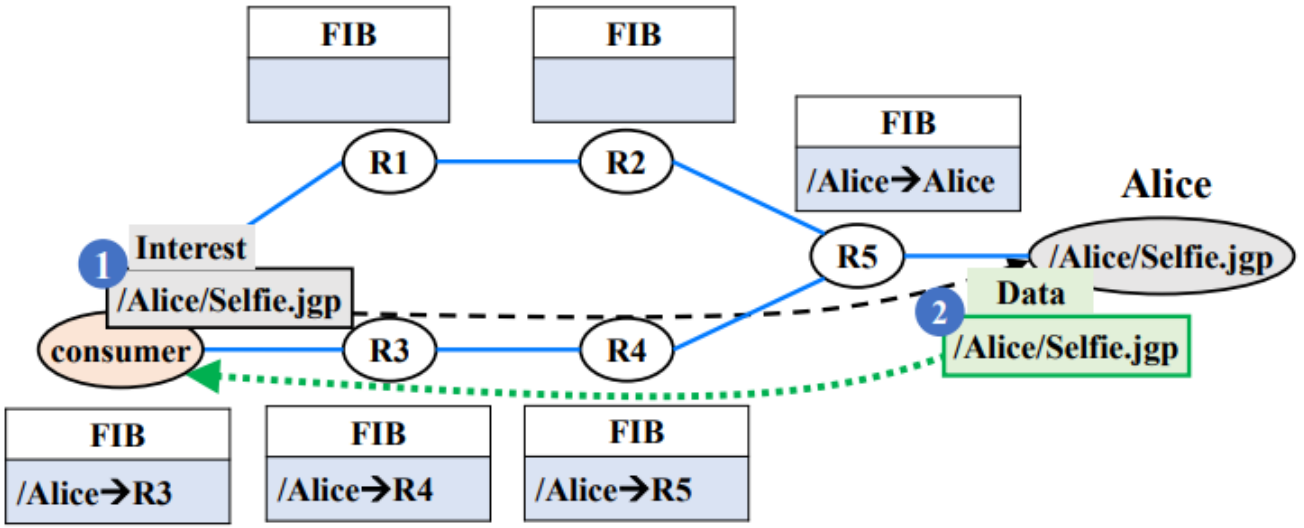
- Consumer mobility is natively support.



Routing Scalability – Solutions

b) Tracing-Based Solutions

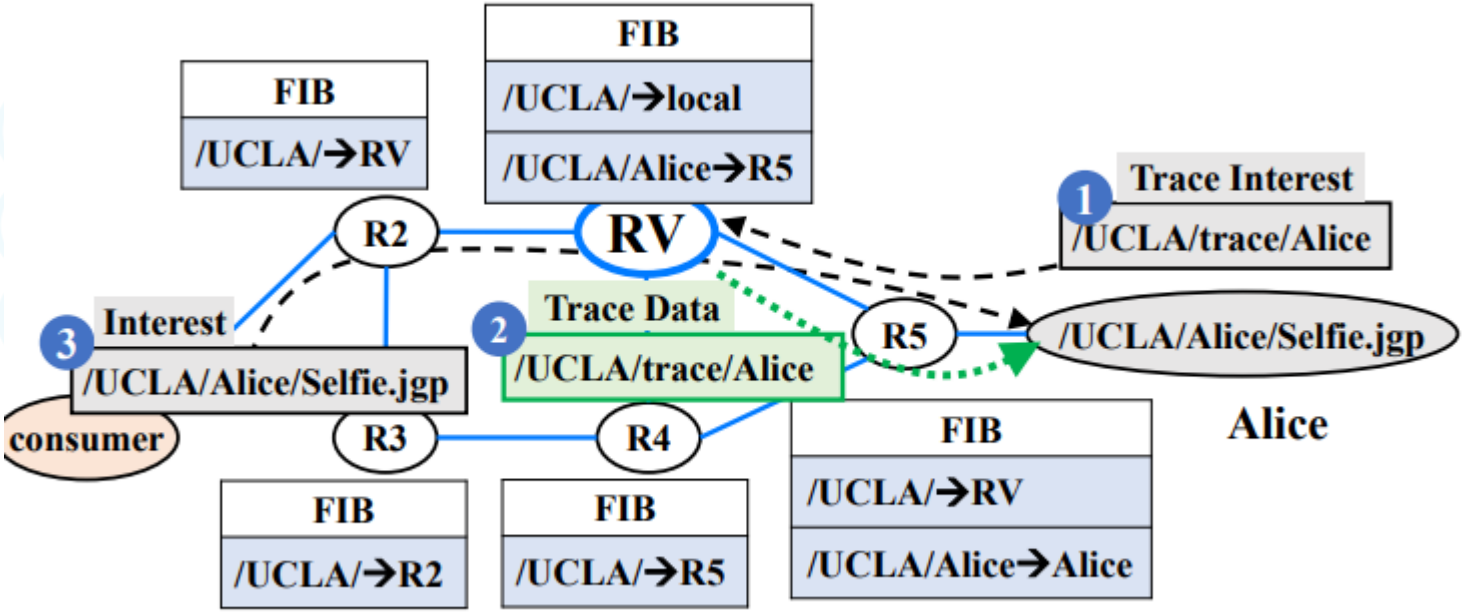
- Self-learning Routing



Routing Scalability – Solutions

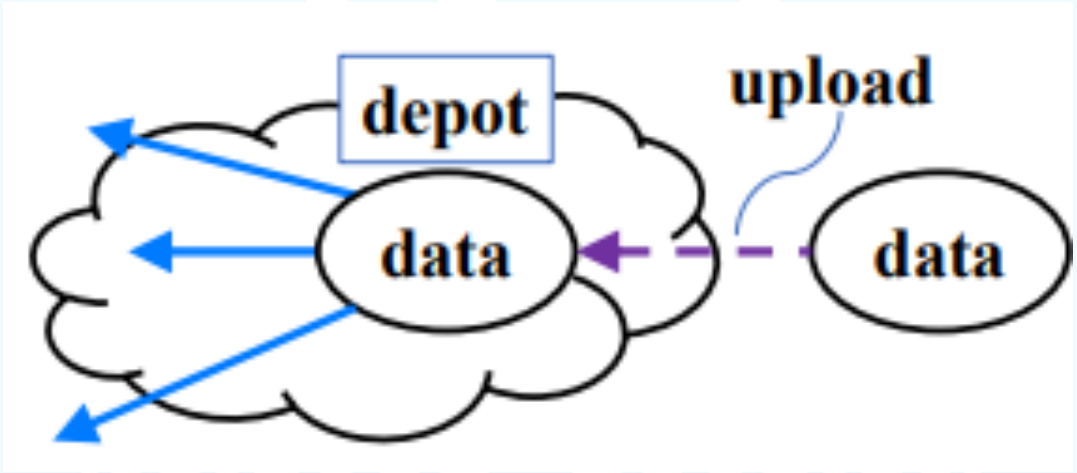
b) Tracing-Based Solutions

- KITE: Producer Mobility Solution, with rendezvous point.



Routing Scalability – Solutions

c) Data Rendezvous (Data Dopt point)



Routing Scalability – Solutions

d) Address Aggregation

- IP network is easier to summarize.
- In general the **ICN summarization is more complicated** due to:
  - The addressing focus is content
  - The content may be provided by an intermediate node
  - A collection of contents from certain producers may be spread on different intermediate nodes.
- The research on address aggregation on the content oriented network was intensely performed on p2p networks using **DHT.**

Routing Scalability – Solutions

f) Routing Labels [5]

- Interest packets will carry a **partially ordered set of routing labels.**
  - Routing labels identify **where the data in question is present**
  - Label could represent a server, a subnet, a data center, a large aggregate route
- Use partially ordered list of content labels to compress the content-name → routing-label lookup database
  - Once again, use **exact match** instead of longest-prefix match

Routing Scalability – Solutions

f) Routing Labels (example)

- Client gets **ID1** from an email
- Lookup returns labels ***{gomommy.com_L_USE1_DC1 | gomommy.com_L_US}***
- Interest packet carries the ID and routing labels
- GoMommy has a **global routing advertisement** for their US AS ***gomommy.com_L_US***
- **Within their AS**, GoMommy has a route advertisement for ***gomommy.com_L_USE1_DC***1 towards their US East Data Center 1
- The load balancer which enters their data center sees the **Content-ID**

Forwarding Scalability - issues

- Key issues in design of a scalable NDN forwarding plane
  1. **Exact string matching with fast update**
     - Exact string matching with fast updates is performed in **PIT lookup** or **Contet strore** lookups.
     - On worst case, every packet requires an update
  2. **Longest prefix match for variable length and unbound names**
  3. **Large scale Flow maintenance**

We Now(From 2022) have a 100Gbps Forwarding-Plane with NDN-DPDK

On economic, societal, and political aspects in ICN

1. **Names as Commodity**
2. **Power Relations in ICN**
    1. **Power over data naming**
    2. **Power over name ownership**
    3. **Power over data retrieval**
3. **Information Centric Trust**
    1. **Trustworthy data provision**
    2. **Trustworthy namespace management**
    3. **Trustworthy data discovery and delivery**
4. **Accountability in ICN**
    1. **Accountability in data inquiry and provision**
    2. **Accountability in namespace and name allocation**
    3. **Accountability in data discovery and delivery**
5. **Private Communication**
    1. **Private as restricted**
    2. **Private as covert**
    3. **Private as confidential**

Recent Topics

- Integrate ICN and 5G
- **Different applications on the ICN**
- Different ICN architecture
- Blockchain and ICN
- Cache Management
- Cahce Strategy
- NDN and CDN
- Congestion Control on NDN
- **Economic, Societal and Political**
- NDN and Different Data Context
  - For example Gnomic Data
- **High Performance Forwarding**
- **Network Management**
- **Migration from TCP/IP to NDN**
- Namespace Management
- Network Measurement
- **ICN Scalability**
- SDN on the NDN
- Security Concepts
- Transport Layer
- using ICN and NDN on IOT
- mobility support in NDN
- **AS sructure and BGP**

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Thanks for Listening