Taxonomy and Comparative Study of NDN Forwarding Strategies

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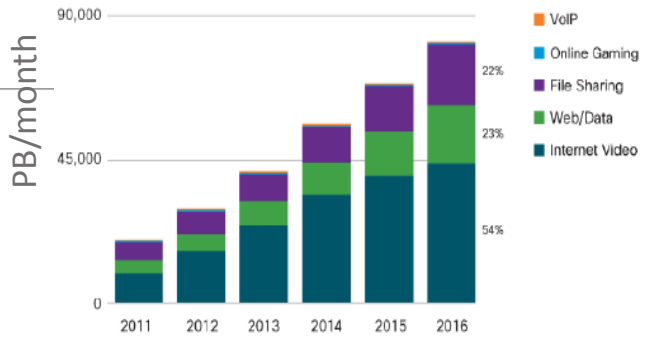
Outline

- Introduction
- Overview of Named Data Networking (NDN)
- Taxonomy of NDN Forwarding Strategies
- Comparison Study of NDN Forwarding Schemes
- Conclusions

Introduction

- Internet data traffic has grown significantly due to the rapid growth in demand for multimedia content.
- Recent statistics show that:
  - over 6 billion hours of video are watched each month on Youtube
  - with 100 hours video uploaded every minute in 2013 (50\% more than 2012).
  - More than 350 million images are uploaded on Facebook each day.

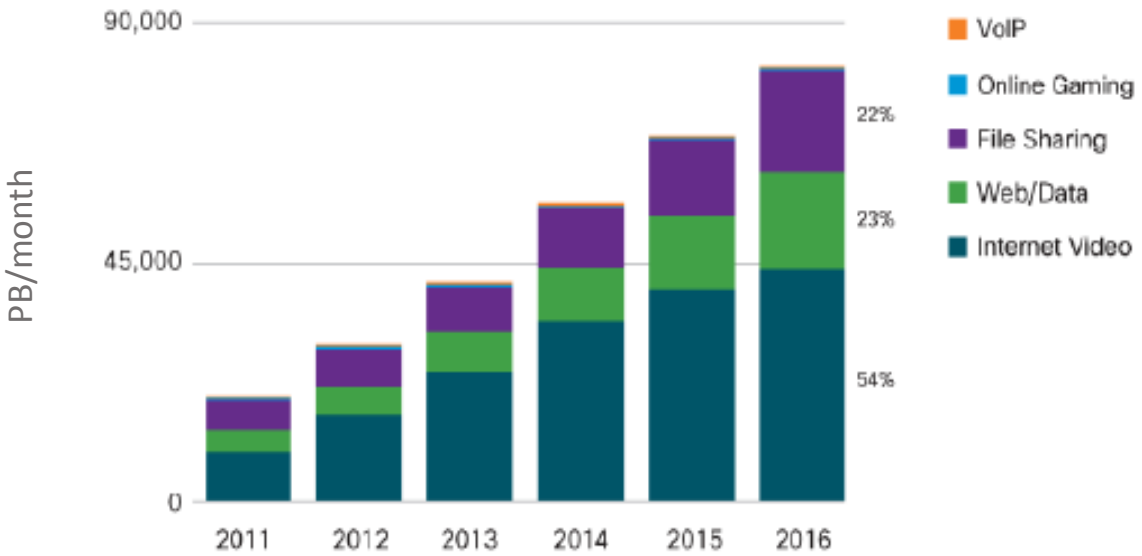


Internet Traffic Forecast [Cisco]

67 % of Internet Traffic

Introduction

67 % of Internet Traffic



Internet Traffic Forecast [Cisco]

→ Users are more interested in data (content) than in end-to-end communication

Introduction

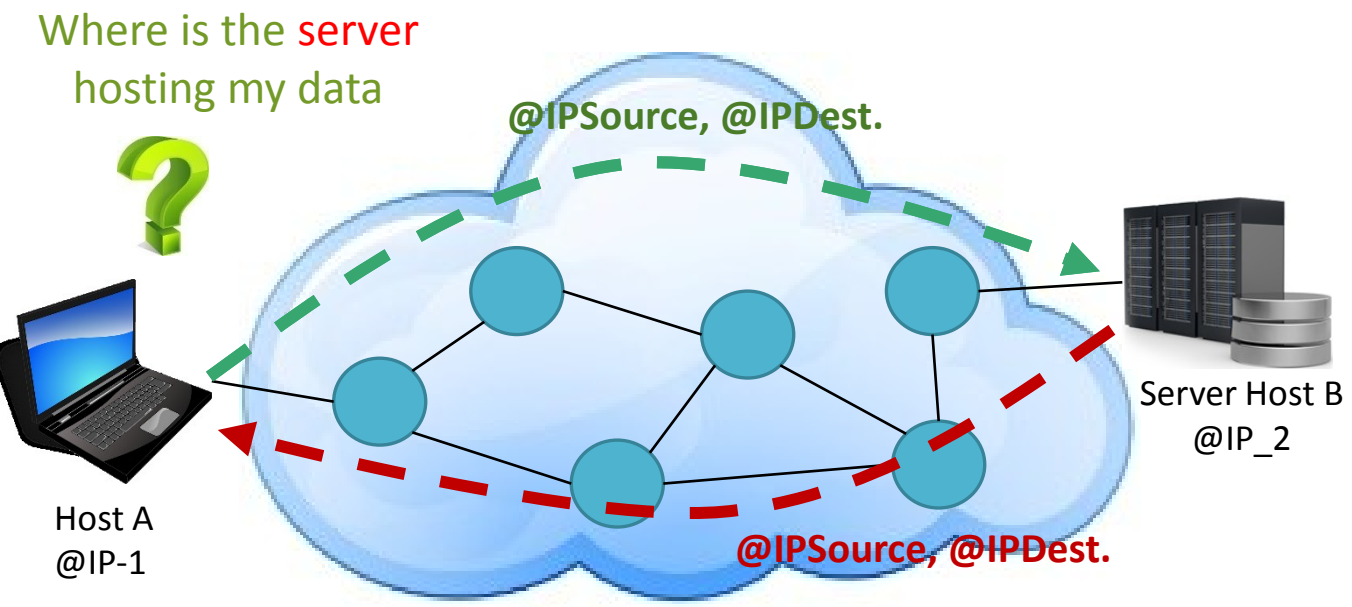
Today's Internet

- End-to-end host communication
- Communication centered around host addresses

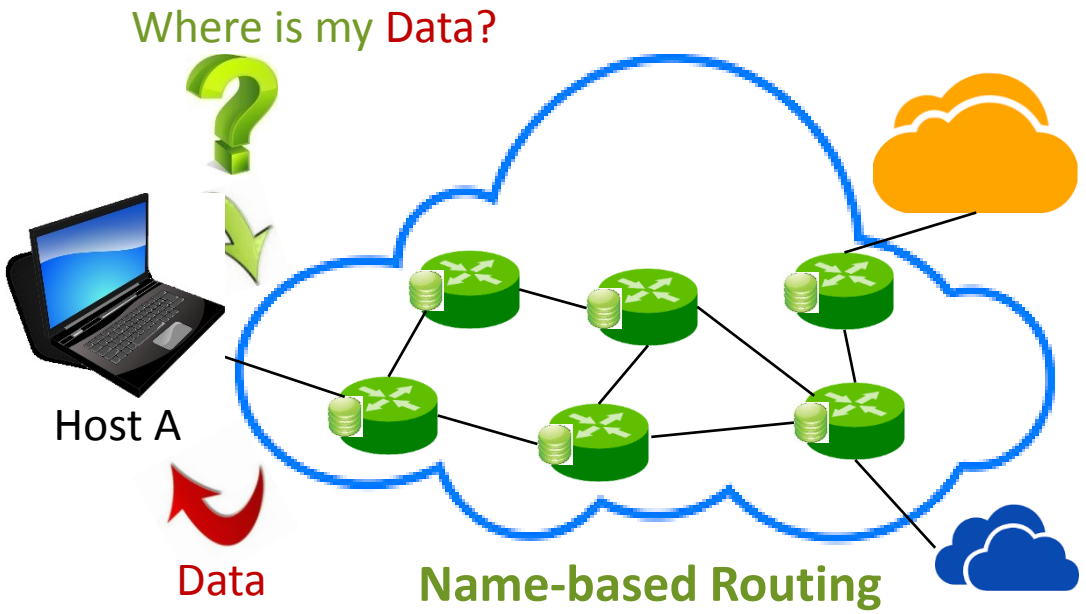
Internet usage has shifted

Named Data Networking

- New communication model is known
  - Communication centered around data
  - focusing on data content names instead of the addresses of the end-to-end hosts.



IP based Routing



Name-based Routing

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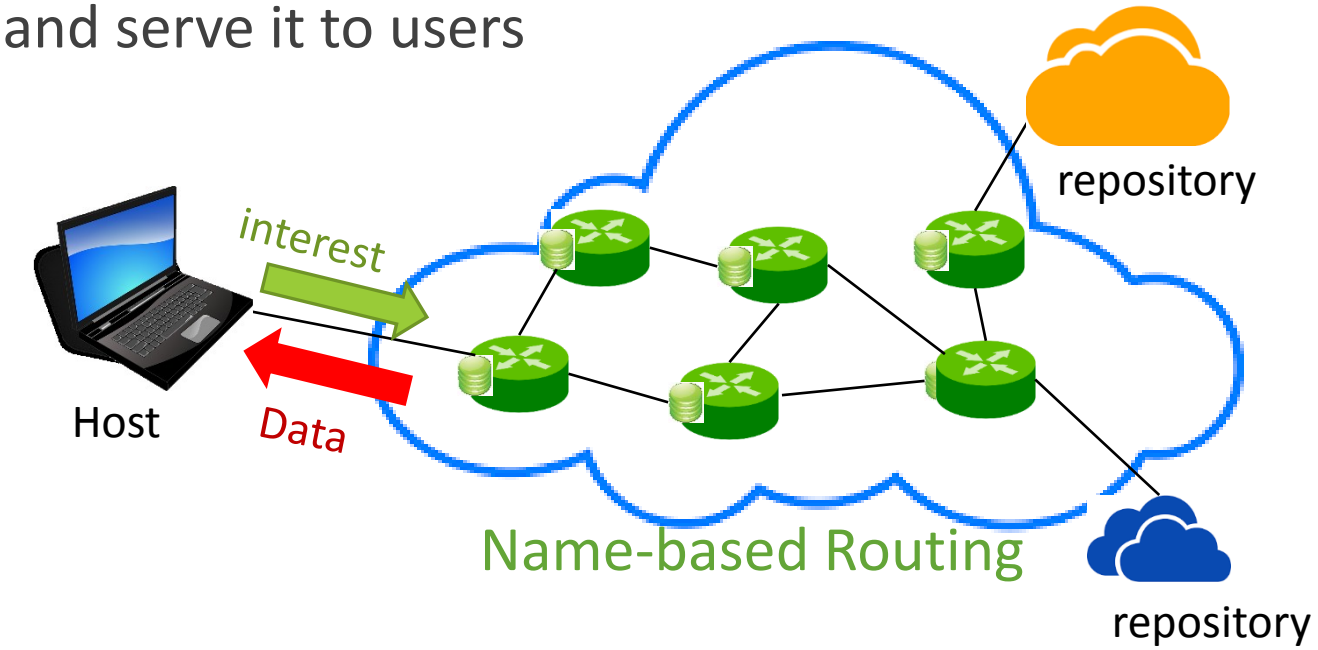
Named Data Networking (NDN)

- Promising candidate for the future Internet architecture
  - Centered around data
  - Data (content) is identified by a name
  - A router can keep the data in its cache and serve it to users

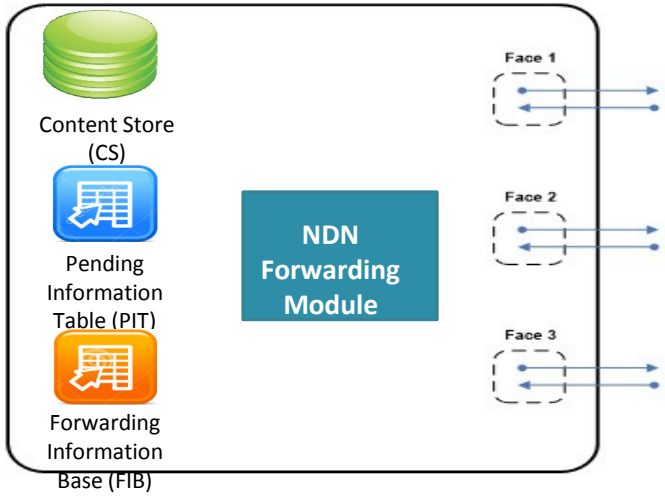
- Two types of packets
  - Interest packets: containing the name of the requested data
  - Data packet



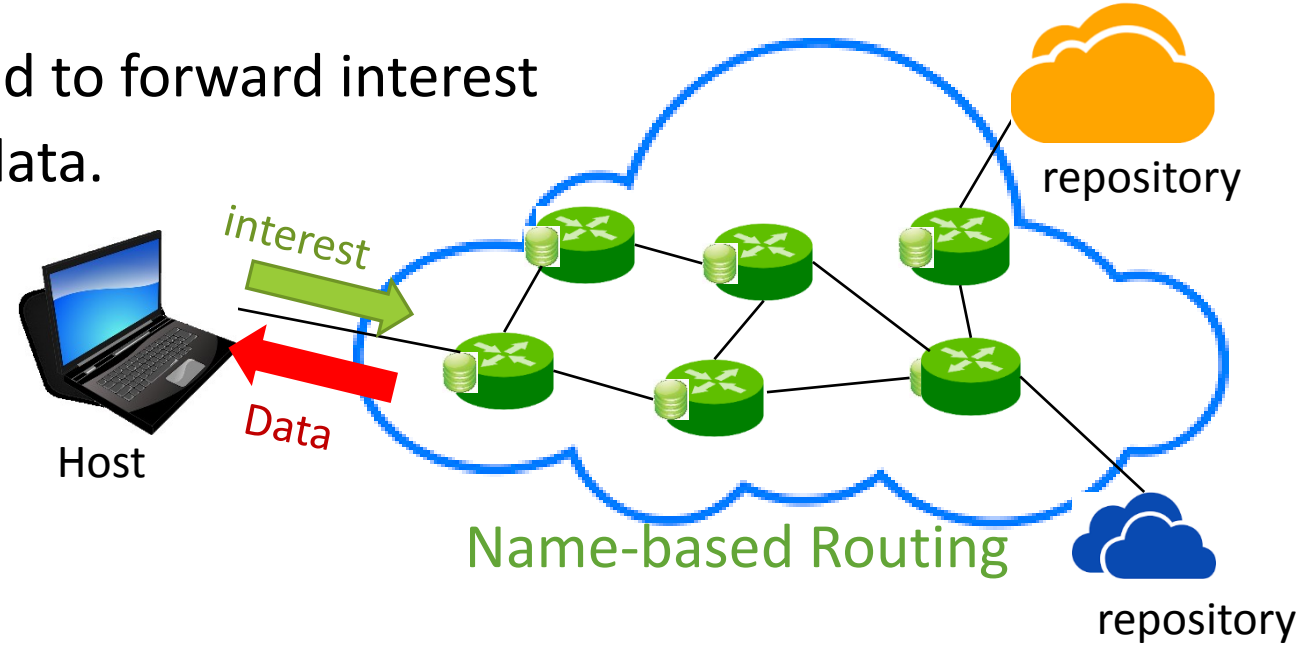
Content Store : a cache of data packets that the router has received

Named Data Networking (NDN)

- NDN router maintains three data structures
  - Content Store: temporary cache data packets
  - Pending Interest Table (PIT) : keeps track of the unsatisfied interest packets forwarded through the router
  - Forwarding Information Table (FIB) : used to forward interest packets towards the potential sources of data.



NDN **Router** Structure

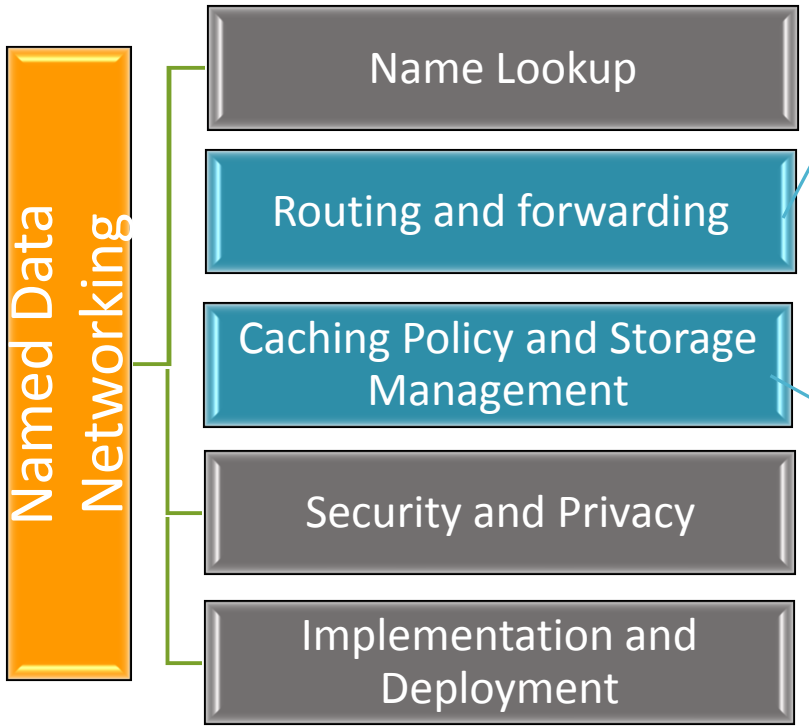


Content Store : a cache of data packets that the router has received

NDN Challenges

➔Numerous challenges should be carefully addressed in order to make NDN a viable technology

➔NDN suffers from a problem of inefficiency of its default **caching and forwarding modules**.



- **Basic Forwarding approach:** Content requests are forwarded to all available interfaces in the FIB entry matching the requested content's prefix except the incoming one.
  ➔High overhead

- **Basic Caching strategy:** a copy of the requested data is stored in all intermediate routers along the path from cache hit node to the user

  ➔High cache redundancy in the network

Our Goals

1. Propose a new taxonomy of NDN Forwarding Strategies

2. Provide a comparison study of the main NDN Forwarding Schemes

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Taxonomy of NDN Forwarding Strategies

NDN Forwarding Strategies

Strategies Based on Routing History Traces

- S-BECONS
- CLS
- SAC
- **COBRA**
- …

Strategies Based on Exploration Step

- **INFORM**
- Probabilistic Forwarding (EPF, MDPF)
- …

Strategies Based on Preselected Responsible Routers

- CollaCache
- CoRC
- **CCFS**
- …

Strategies Based on Explicit Cache Coordination

- **NbSc**
- ACCCP
- SCAN
- …

NDN Forwarding strategies

NDN Forwarding Strategies
Basic NDN
COBRA
INFORM
NbSc
CCFS

NDN Forwarding strategies

NDN Forwarding Strategies
Basic NDN

- Forwarding based on flooding .
- Leaving a copy of data in the in-path nodes.
- On receiving an Interest: Router checks first its local CS.
    - Data returned if exists
    - Otherwise, the router adds the incoming interface in PIT if there is an entry, if not it will be sent following the FIB routers.
    - Data will be returned back when a hit occur.

☹ Forwarding operates independently of caching

☹ Neglecting the closed copy in the vicinity

V. Jacobson, et al., “Networking named content,” in International Conference on Emerging Networking Experiments and Technologies (CoNEXT), 2009, pp. 1–12.

NDN Forwarding strategies

NDN Forwarding Strategies
Basic NDN
COBRA

- Uses Stable BloomFilters (SBF) to leave traces of retrieved contents
- Replaces classical FIB by a SBF-based FIB
  - As many SBFs as the router's interfaces.
- On receiving an Interest => Performs an interface ranking based on Longest Prefix Match (LPM) (at each lookup).
  - The more a SBF matches name content, the higher the associated interface is ranked.
  - the most ranked interface is used

-Does not **scale** with the network size.

-COBRA will converge to the Basic NDN .

M. Tortelli et al., "Cobra: Lean intra-domain routing in ndn," CCNC, Jan. 2014.

NDN Forwarding strategies

NDN Forwarding Strategies
Basic NDN
COBRA
INFORM

Exploration phase: Interests are forwarded via randomly chosen faces in addition to the default FIB faces

- Discovered sources of content are then added to the FIB
- Adding discovered sources of content to FIB

- **Exploitation phase**: node uses this information to forward the content request towards the closest available cached content copy in terms of estimated residual delay.

Interesting proposed learning framework

Randomly replicating and flooding Interests to all nodes faces could end up with face congestion problems and scalability issues.

R. Chiocchetti et al., "Inform: a dynamic interest forwarding mechanism for information centric networking," ACM SIGCOMM Worskhop, Jul. 2013.

NDN Forwarding strategies

NDN Forwarding Strategies
Basic NDN
COBRA
INFORM
NbSc

- ***Neighborhood Search protocol***:
  - Exchanges periodically cache BF summaries (Bloomfiter based) between immediate neighbors .
  - Received BFs are stored in a neighbor table
    - used to check the content availability in the neighborhood in the case of a cache miss.
- ***Cooperative caching strategy based on a Cachebit algorithm*** :
  - Using a bit in the content header to indicate whether a data content has already been cached along the path
  - Admission control policy : if cache bit setten=> Prevents the downstream nodes to cache data.

Improving the chances of off-path content discovery.

Limits the availability of in-path data

W. Wong, et al., “Neighborhood search and admission control in cooperative caching networks,” IEEE GLOBECOM, Dec. 2012.

NDN Forwarding strategies

NDN Forwarding Strategies
Basic NDN
COBRA
INFORM
NbSc
CCFS

- Divide the network into **domains** managed by cooperative controllers
- Each domain : **1 Controlling router** + **Regular NDN Routers**
- Each controller has a global cache view (intra and inter-domain)
- Each controller is responsible for taking interest forwarding decisions and ensure the availability of high popular data in its domain
- Hybrid cache coordination approach: implicit intra-domain and explicit between neighbor Controllers

☹ Consider additional objectives: Load balancing among controllers

N. Aloulou, et al., "A Popularity-driven Controller-based Routing and Cooperative Caching for Named Data Networks", Network of the Future, NoF 2015, Montréal, Canada, October 2015

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Qualitative Comparaison

➔we consider the following main criteria.

- **Additional information:** a complementary structures as a part of their design
- **Cache visibility:** the scope of awareness regarding in-network cached data.
- **Cache coordination:** the method used for coordinating storage decisions between cache nodes
- **Popularity-driven:** takes into consideration the content popularity or not
- **Searching policy:** defines the way to search a content when an Interest is received before taking the forwarding decision.
- **Caching and forwarding operational mode:** coupled mode when the caching and the forwarding decisions are jointly considered and uncoupled if they are independent.

Qualitative Comparaison

Solution	Additional-Info	Cache visibility	Cache coordination	Popularity-driven	Searching policy	Caching & forwarding operational mode
Basic NDN	No	Local	Noncooperative caching	No	default NDN	Uncoupled
COBRA	FIB modified by adding SBFs and interfaces Ranks to each entry	Local	Implicit	No	Query forwarding according to routing hints established by SBF-based FIB	Uncoupled
INFORM	FIB modified by adding Q-Values	Local	Noncooperative caching		Q-Routing	Uncoupled
NbSc	Neighborhood index Table	Local+ neighborhood	Explicit	No	Neighbor-hood Search based on index table	Coupled
CCFS	Cache Information Base (CIB)	@regular routers: local; @Controllers: neighborhood	Implicit(intra-domain) & explicit (inter-domain)	Yes	Controller- based query forwarding according to index tables (FIB and CIB) based on the popularity of the requested content	Coupled

Simulation setup

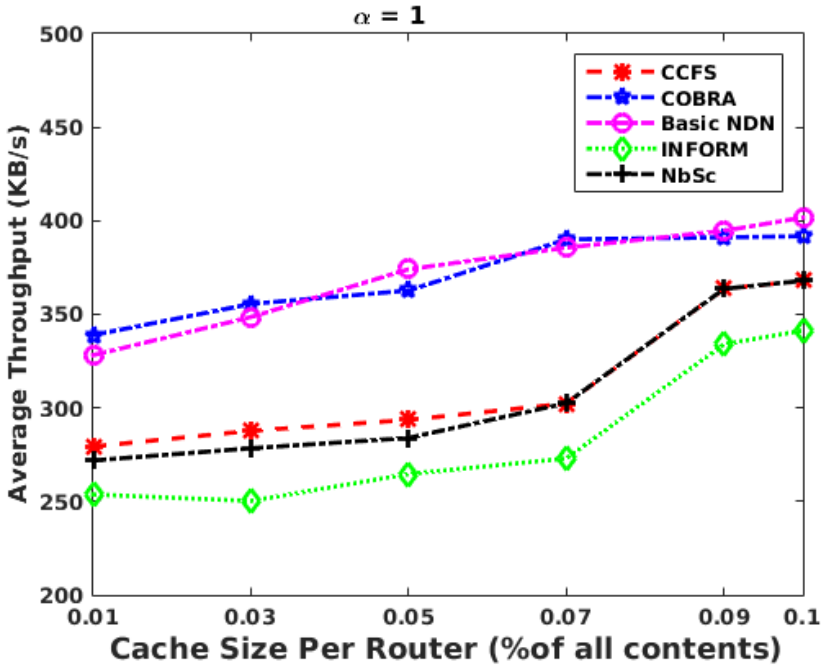
- We compared Basic NDN, COBRA, INFORM, NbrSc and CCFS
- Performance Metrics
  - Mean Latency: time refers to the average time taken by a complete content (i.e., a file)
  - Throughput: the average amount of data received successfully by a client in one second
  - Interest overhead: the data retrieval overhead generated in the network
  - Cache Hit Ratio: fraction of requests served by the cache.
- We studied the impact of the variation of the Cache size Per router

Simulation setup

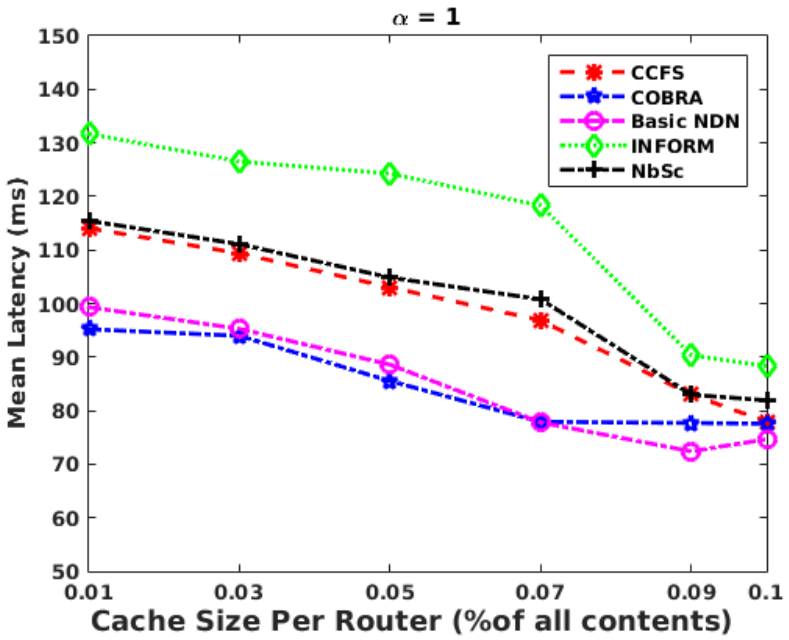
Parameter	Value
Chunk size File size Catalog size Cache/catalog ratio	10 KB Uniform distribution (100 chunks per file ➔ average file size =1MB) 10^6 files {0.01 % ..0.1 %} of all Content
Zipf exponent α Request rate (per client)	{0.8,1,1.2,1.4} 50 chunks/s
Cache replacement policy	Least frequently Used (LFU)
Network simulator Number of interests per user Simulation duration	NDN-sim 90000 48 hours
Network topology	Geant network (22 core routers, 73 edge routers and 255 clients)

Simulation Results

Impact of Cache Size



(a)



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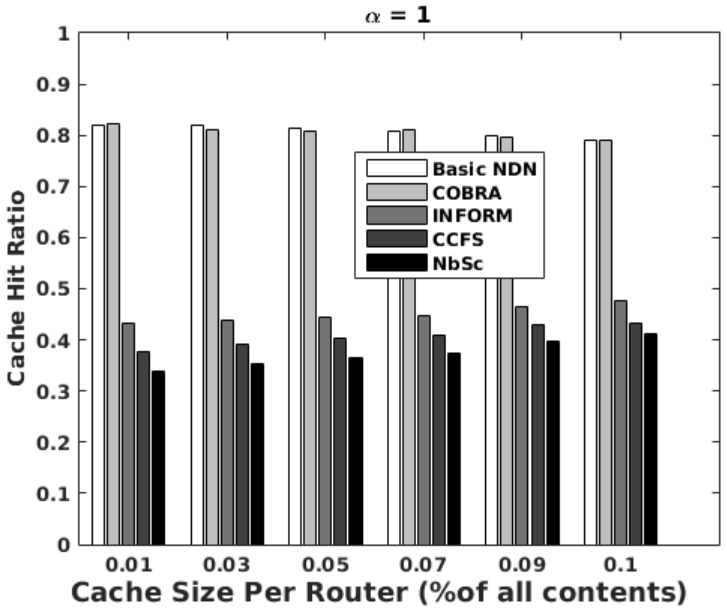

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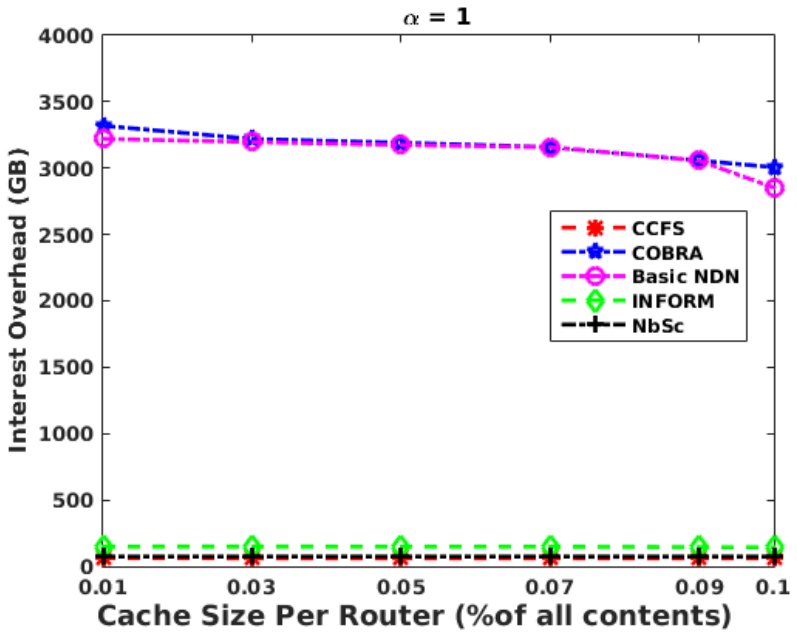
Simulation Results

Impact of Cache Size



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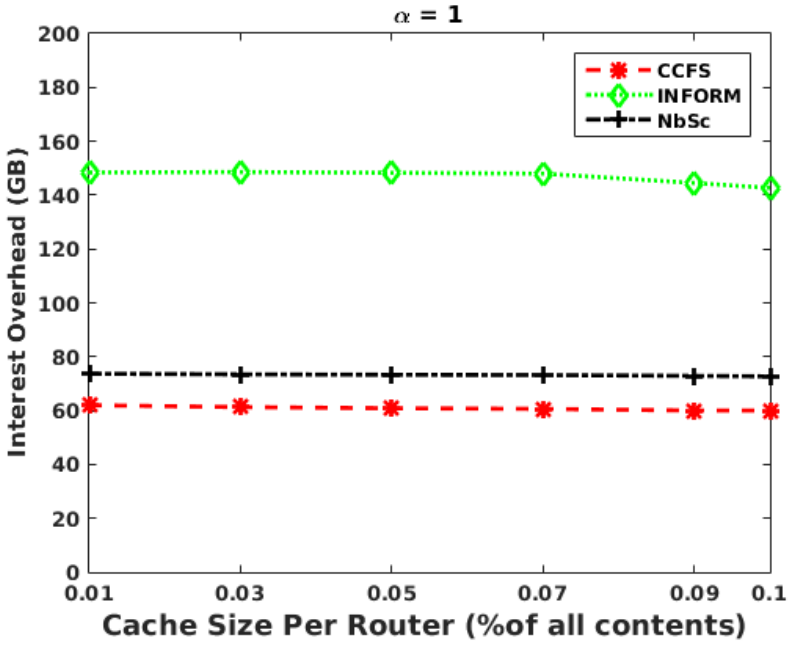

(b)

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Conclusions

- Propose a new taxonomy of NDN Forwarding strategies
  - Classify the NDN forwarding strategies into four categories based on their basic functional designs to support the Interest forwarding decision
- Survey the main proposals and identified their advantages and limitations
- Main Observations
  - A coupled operational mode of Caching and Forwarding schemes reduces significantly the Interest Overhead in the network
  - A Popularity-driven design improves the forwarding efficiency

Thank you for your attention

Any question?

CCFS Overview

CCFS

Controller-based Forwarding Strategy

- If a router has the requested data, it sends it back to the user
- Otherwise, the interest has to be handed up to the controllers

Hybrid cache coordination

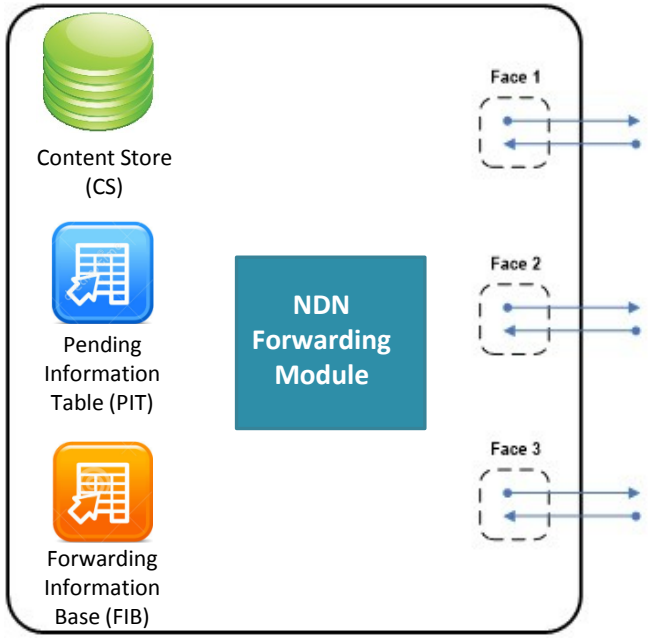
- Implicit intra-domain coordination: The controller implicitly builds a cache view of the content stored in its domain
- Explicit inter-domain coordination: Each Controller periodically informs neighboring controllers about available data in its domain

Popularity-driven caching admission policy

- High Popular content is cached in the Controllers CS
- Low Popular content is cached in the Regulars CS

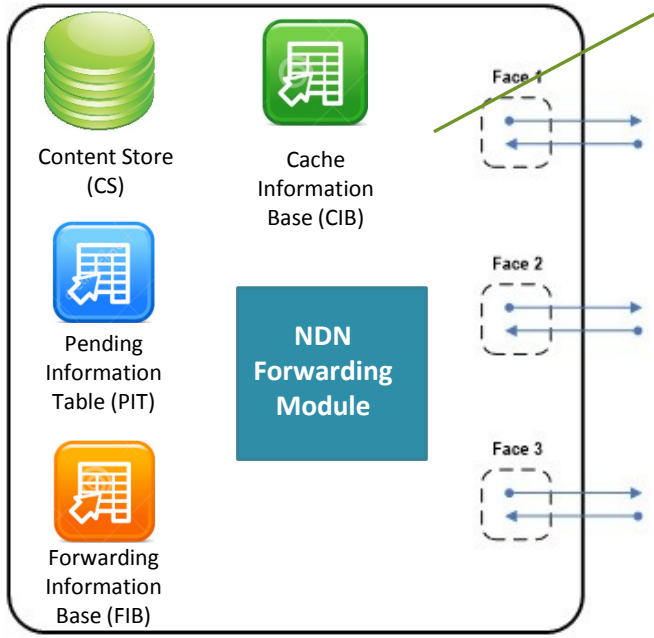
N. Aloulou, et al., "A Popularity-driven Controller-based Routing and Cooperative Caching for Named Data Networks", Network of the Future, NoF 2015, Montréal, Canada, October 2015

CCFS - Overview



NDN **Regular Router** Structure

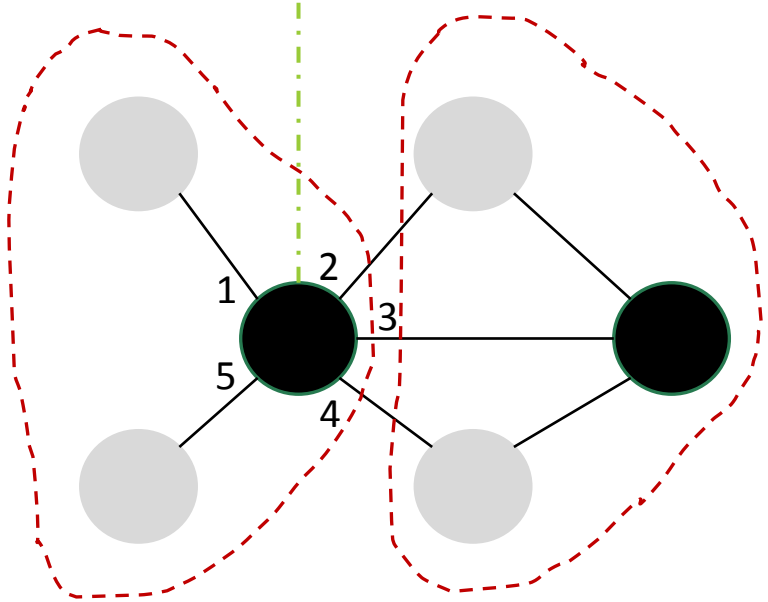
Local cache awareness limited to the CS



NDN **Controller Router** Structure

Local and Neighborhood cache awareness

Face ID	Type	SBF
1	Regular	1010101010010100010
3	Controller	11110000010101011111
5	Regular	00100011111101010101



Cache information base (CIB): a new table that has as many entries as the Controller's interfaces towards local regular routers and its neighbouring Controllers

CCFS - Overview

Basic Idea:

- If a router has the requested data, it sends it back to the user
- Otherwise, the interest has to be handed up to the controllers

<u>Controller</u>: Interest Forwarding

- If there is an entry in the CIB matching the footprint of the requested content

  Forward the Interest to the matching interface
- Otherwise, Forwards the Interest according to the FIB.

<u>Regular</u>: Interest Forwarding

- If the incoming interface is the controller

  Forward the Interest according to the FIB
- Otherwise, Forward the Interest to the controller