Information Centric Networking

MSc in Computer Networking
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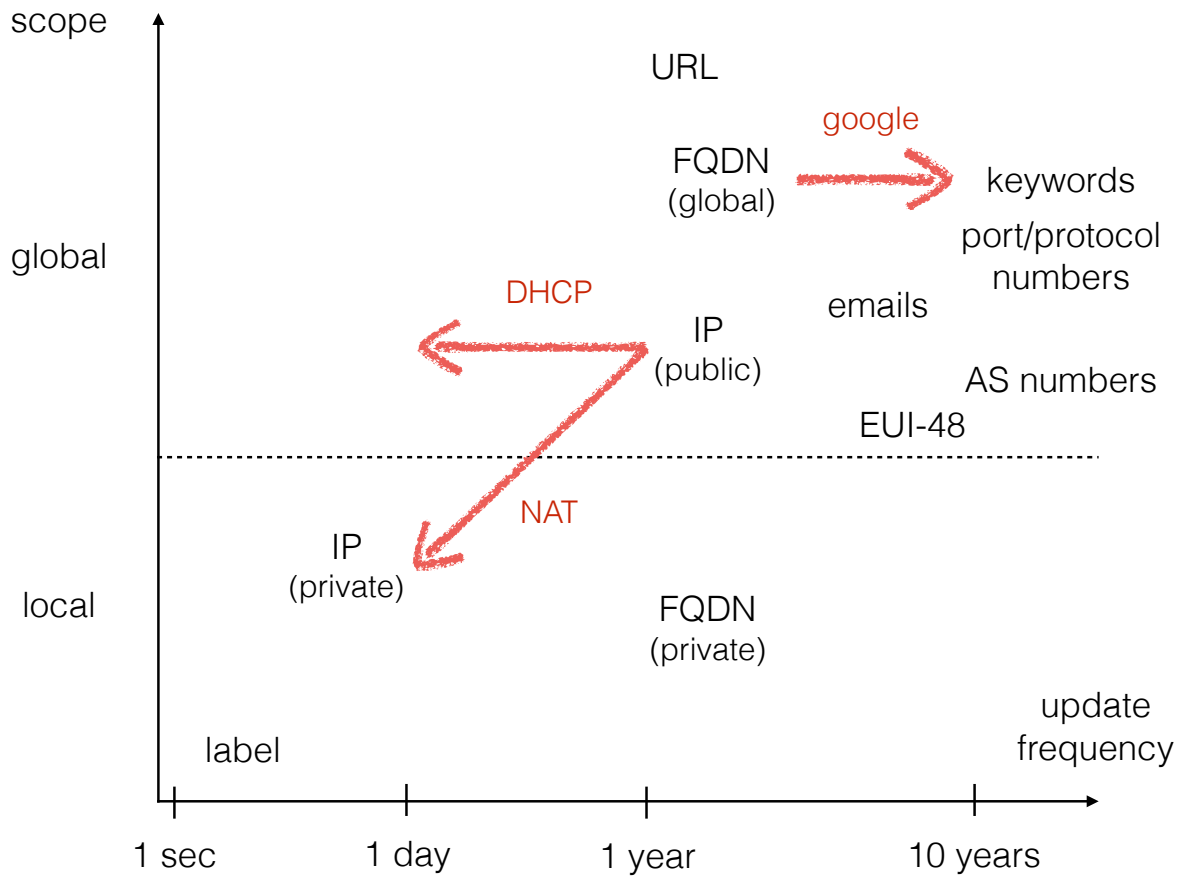
Prométhée Spathis
promethee.spathis@upmc.fr

Once, IP Adresses used to rule the Internet

- RFC 597 Host Status (1973)

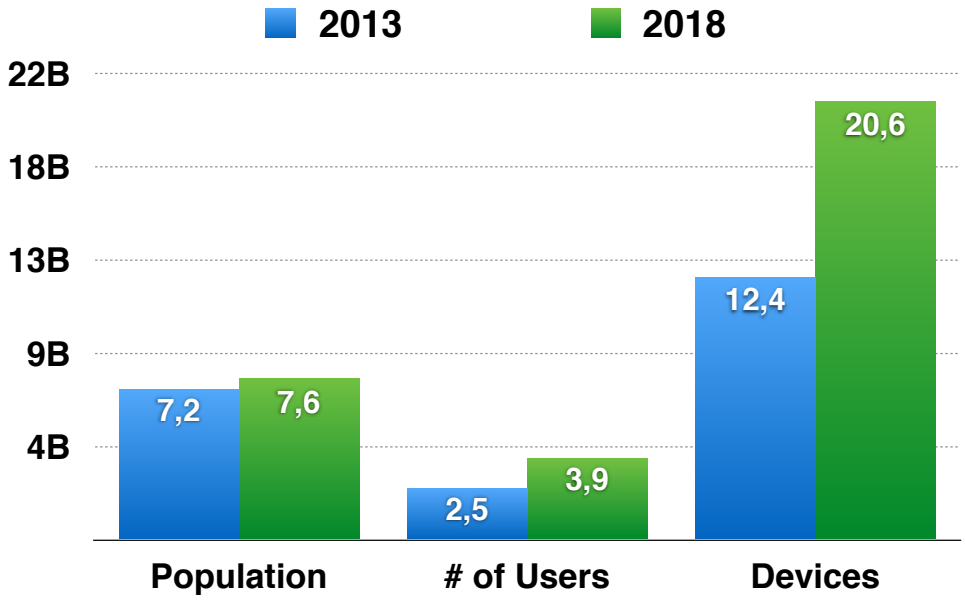
Host (8)	Address (10)	Hostname	(Interface)-> Computer	Status/ System
1	001	UCLA-NMC	Sigma 7	Server till 12/31/73 SEX
			PDP-11/45	User 1/1/74 ANTS
101	65	UCLA-CCn	IBM 360/91	Server
201	129	UCLA-CCBS	(PDP-15)-> PDP-10	limited Server
002	2	SRI-ARC	PDP-10	dedicated Server TENEX, NLS

- RFC 990 (1986)
  - ~10K assigned network numbers



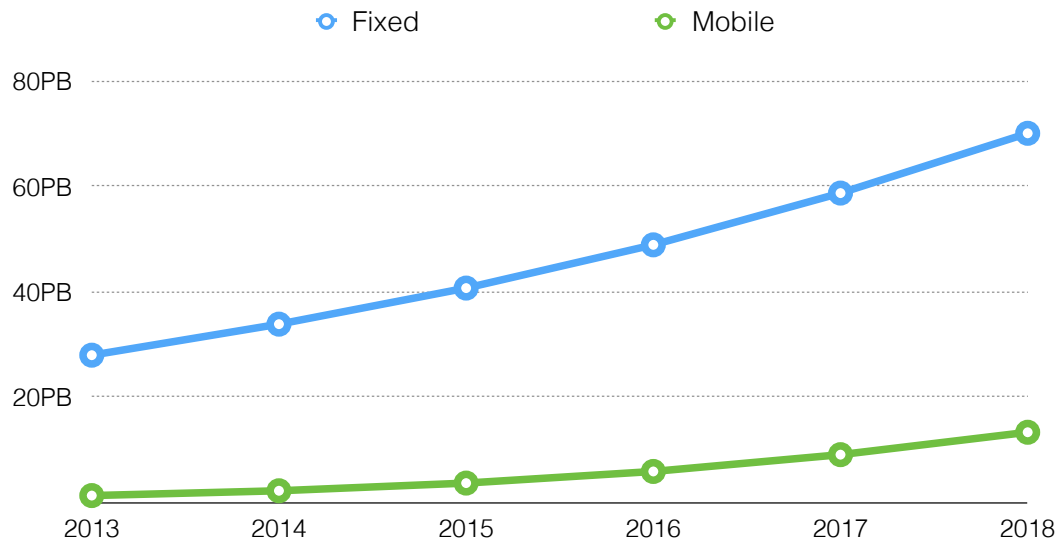
Man vs Human

(Billions per Year)



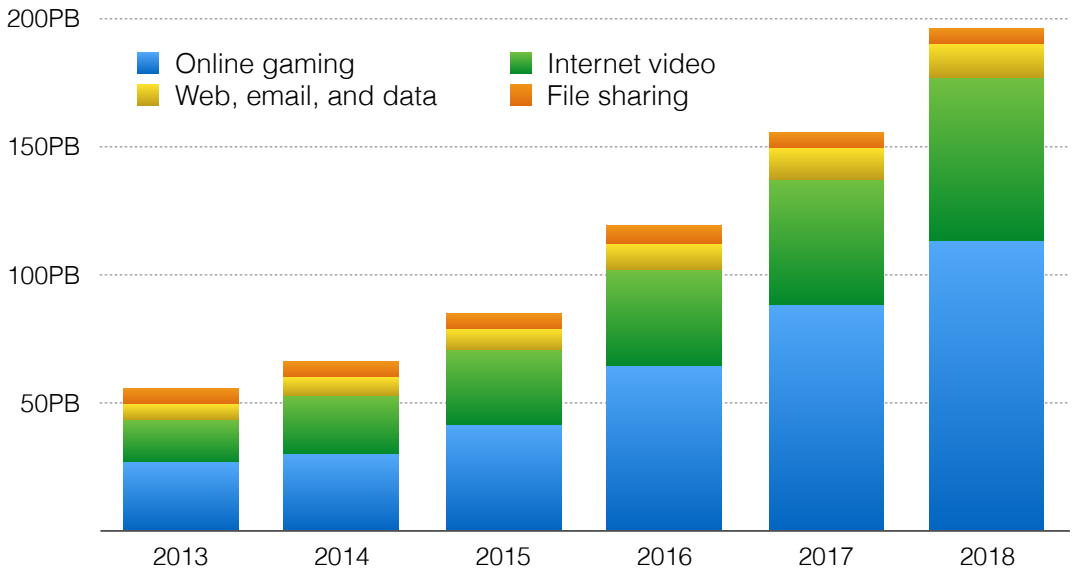
Internet Traffic by Network

(Petabytes per Month)



Internet Traffic By Type

(Petabytes per Month)



IP Addresses Bashing

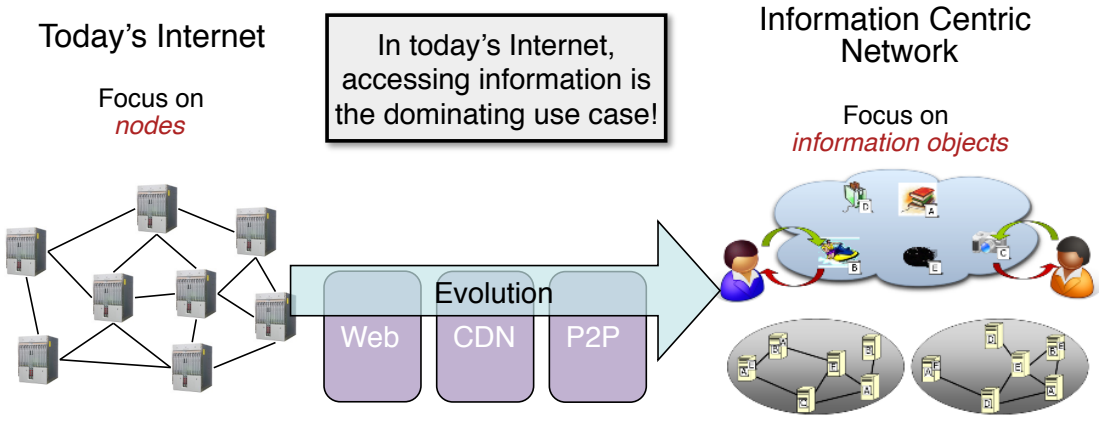
- Mobility/Migration: IP adds change over time
- Multihoming/Replication: Multiple IP adds at same time
- Routing and name resolution: Scaling and convergence time limitations
- Mobility and multihoming: ID/Loc split architectures
- Migration and replication: Data-intensive applications?

Design Usage Mismatch

- Internet was designed for host-to-host communication
  - "contact this host…"
- Internet is mainly used for data access
  - "get me this data....."

- Mismatch between usage and design:
  - data migration and replication unnecessarily hard
  - requires Akamai- and BitTorrent-like designs to scale
  - mobility and multi-homing pose problems

Information Centric Networking



- Considering important requirements
  - **Accessing named resources – not hosts**
  - **Scalable distribution through replication and caching**
  - **Good control of resolution/routing and access**
- With ubiquitous caching
  - But for all applications
  - And for all users and content/service providers

« Named Data Network (NDN) is a general-purpose protocol built on requests for named data. »

— Patrick Crowley (University of Washington in St. Louis)
ACM Conference on Information-Centric Networking (ICN-2014) Paris, France

« Content-centric Networking (CCN) is a communication architecture based on transferring named data. »

— Glenn Scott (Senior Research Scientist and Principal Engineer at Parc)
ACM Conference on Information-Centric Networking (ICN-2014) Paris, France

CCN Timeline

- 2005: PARC starts work on ICN
- 2006: Van Jacobson's talk at Google
- 2007: CCN 0.x begins
- 2009: Seminal CCN Paper at CoNext 2009
- 2010: NSF-funded NDN project
- 2013: CCN 1.x begins
- 2014: NDN 2nd phase (w/o Parc)

1st Dagstuhl Seminar (2010)
1st SIGCOMM workshop (2011)
1st CCNxCon (2011)
1st INFOCOM workshop (2012)
1st ICNRG meeting (2012)
1st NDNCom meeting (2014)
1st ICN Conference (2014)

CCN Key Tenets

- Content centric paradigm
  - access data objects in a location-independent manner
  - secure the content rather then the connection
  - add general-purpose memory into the network
- CCN design is not a clean-state approach …
  - not a replacement for IP
  - … but more conventional

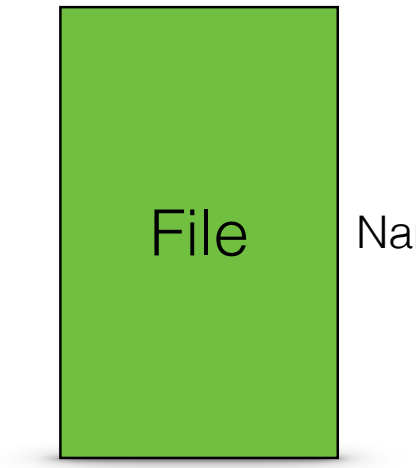
CCN Design Choices

- Which IP engineering principles can remain still valid after removing addresses from the Internet?
- Maximize the reuse of well-tried mechanisms and techniques directly borrowed from IP
  - DNS-like naming scheme
  - CIDR-like prefix aggregation
  - Longest prefix match forwarding
  - Link-state protocols (i.e. OSPF) opaque capacities

Agenda

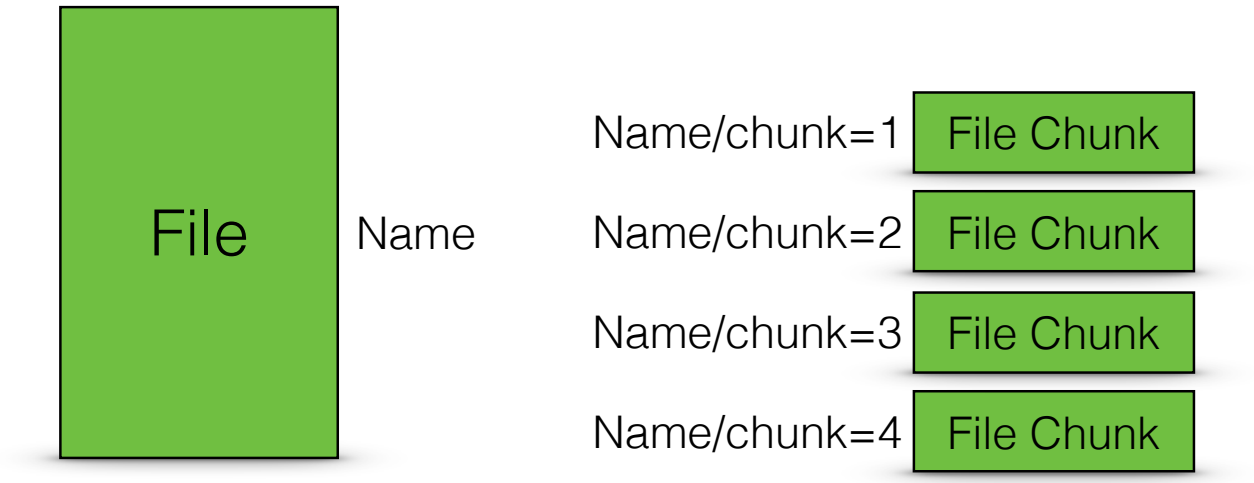
- CCN object and chunks
- CCN names format
- CCN signature
- CCN packet and messages format
- Content-based security
- CCN node model and forwarder
- CCN routing
- Application examples
- Conclusions

Named Object



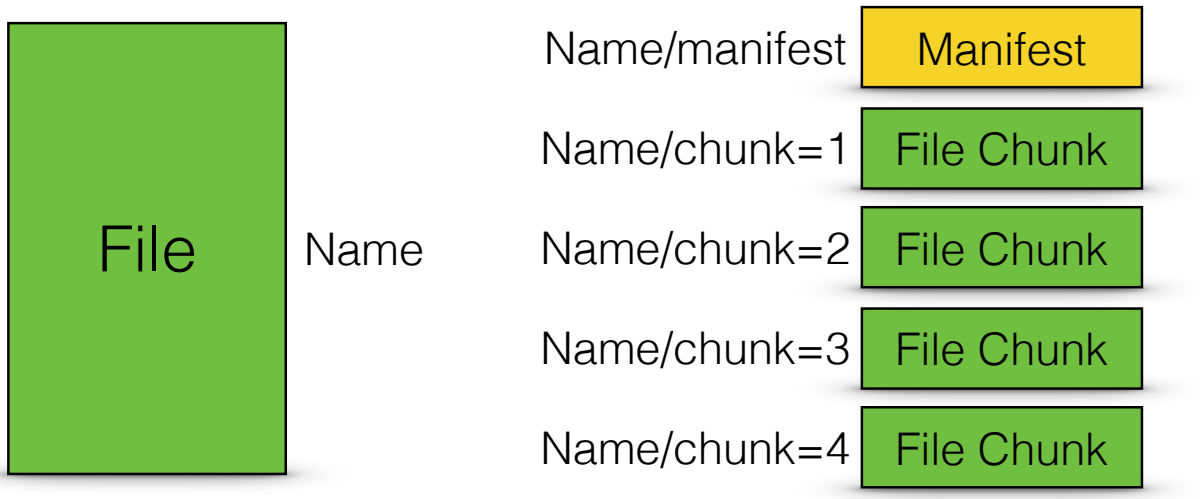
A large object has a CCN publisher-given name

Named Chunks



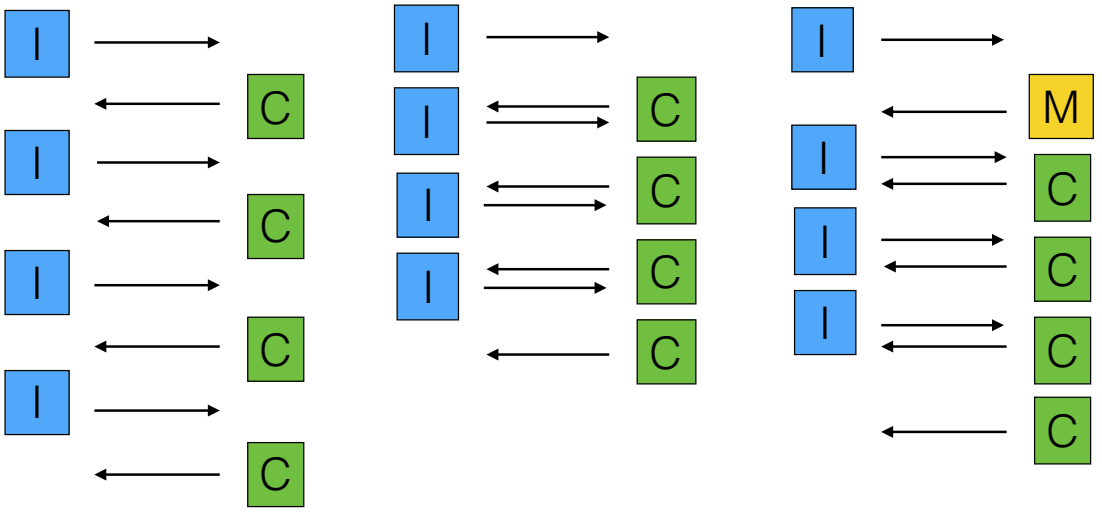
Each network-sized chunk also has a CCN name

Named Chunks



CCN creates a manifest describing the file

Transport Protocols



Core exchange parallel requests use of manifests

CCN Names Format

/upmc/spathis/ccn/tutorial/slide13/v=2/c=0

Ordered labeled sequence of binary segments

CCN Names Format

/upmc/spathis/ccn/tutorial/slide13/v=2/c=0

↓

global routable
name segments

Ordered labeled sequence of binary segments

CCN Names Format

/upmc/spathis/ccn/tutorial/slide13/v=2/c=0

↓ global routable name segments

↓ application dependent name segments

Ordered labeled sequence of binary segments

CCN Names Format

/upmc/spathis/ccn/tutorial/slide13/v=2/c=0

↓ global routable name segments

↓ application dependent name segments

↓ protocol dependent name segments

Ordered labeled sequence of binary segments

CCN Names Qualifier

Interests can identify content hash or publisher's key

/upmc/spathis/ccn/tutorial/slide13/v=2/c=0

ContentObjectHash

↓

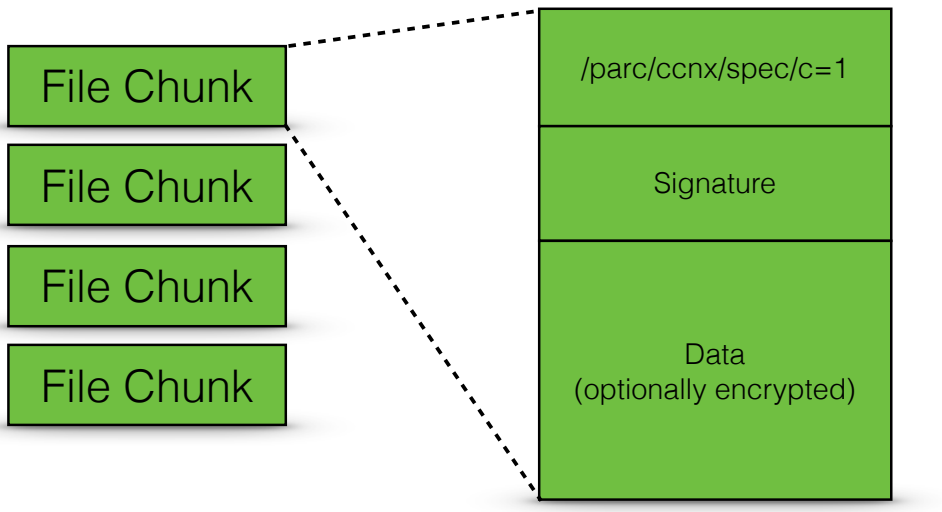
secure cryptographic hash of the Content Object message

KeyId

↓

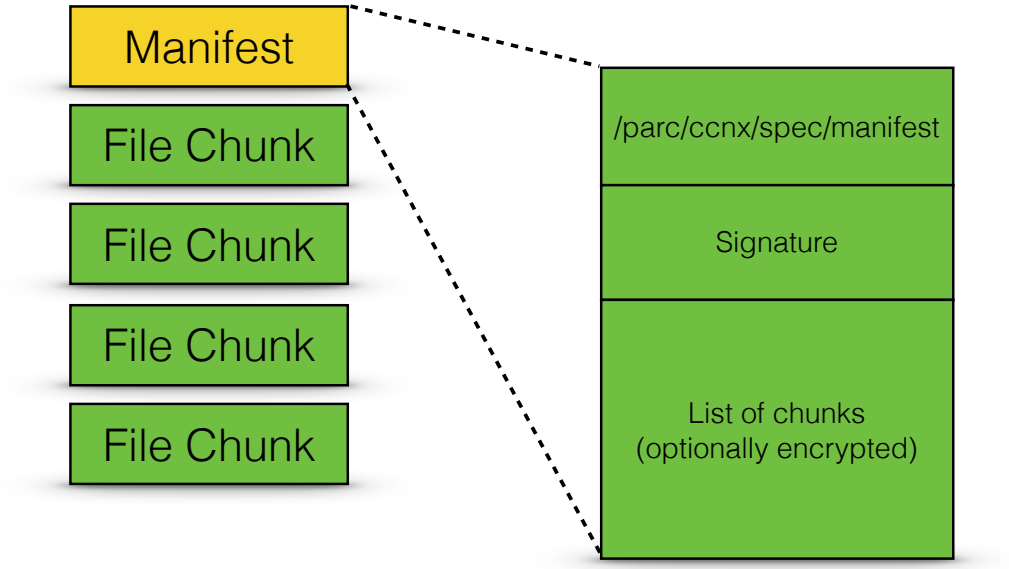
Identifier of the Content Objet publisher

Secure Single Chunk



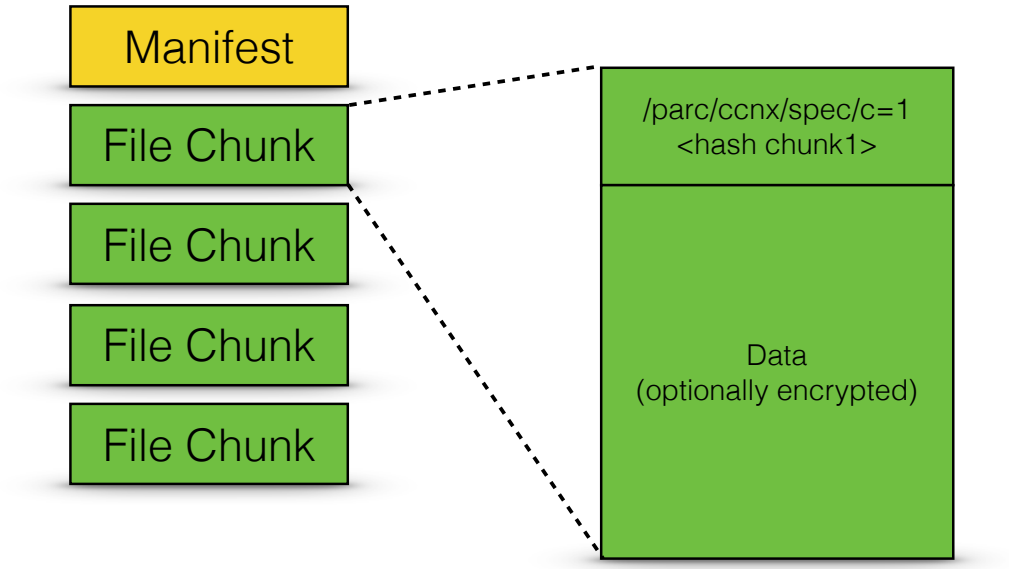
CCN names and signs every chunk

Secure Whole Object via Manifest



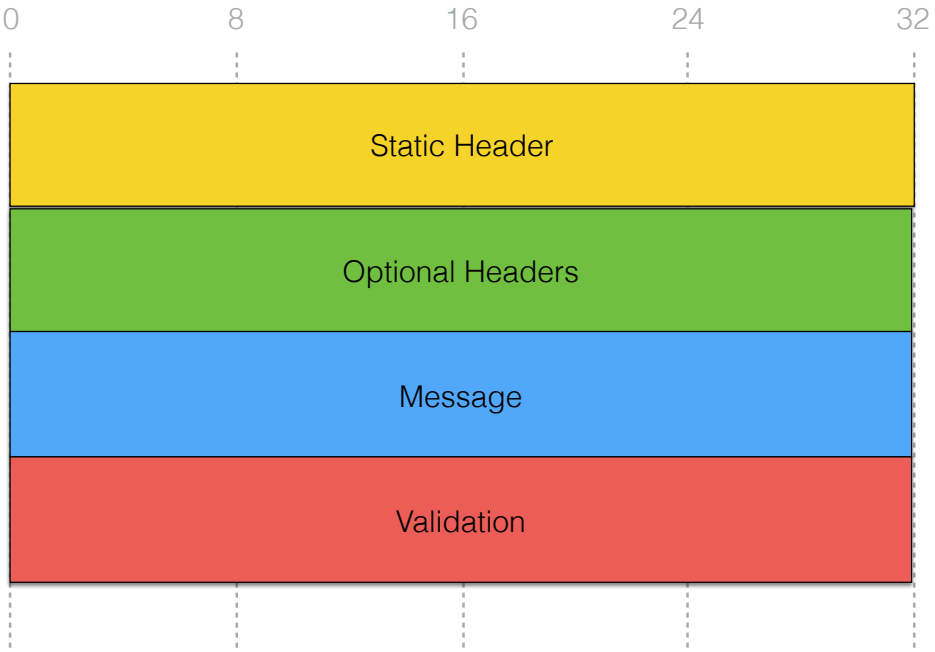
CCN names and signs the file via a manifest

Secure Whole Object via Manifest

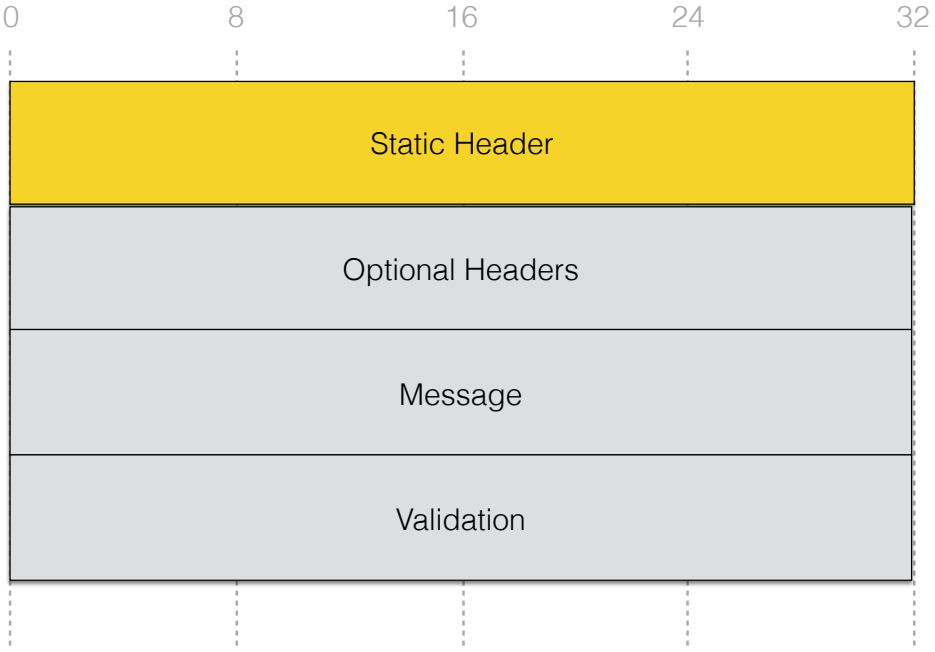


Indirectly sign every chunk through the manifest

Packet Format



Static Header



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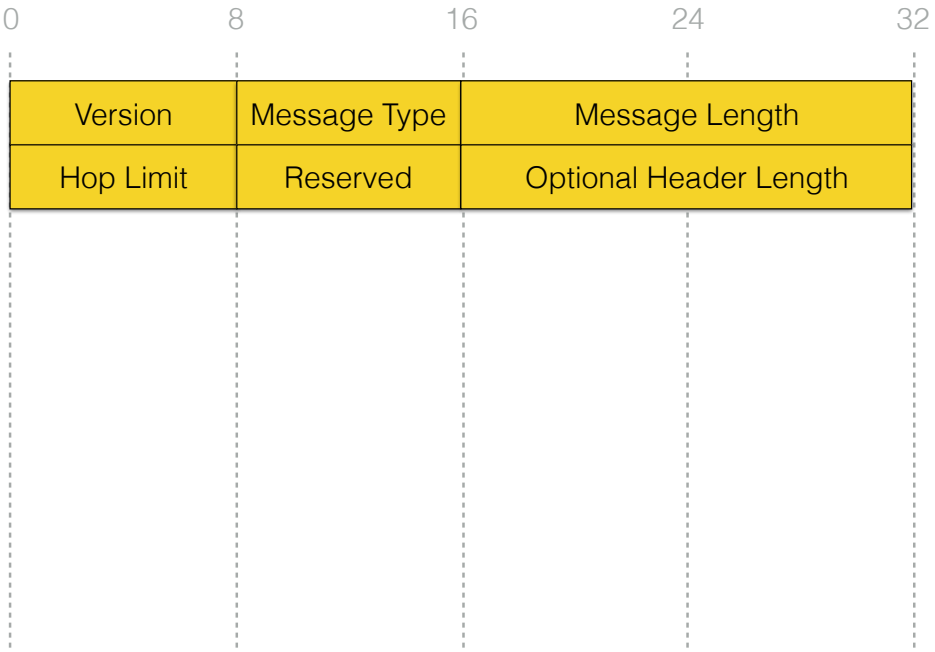
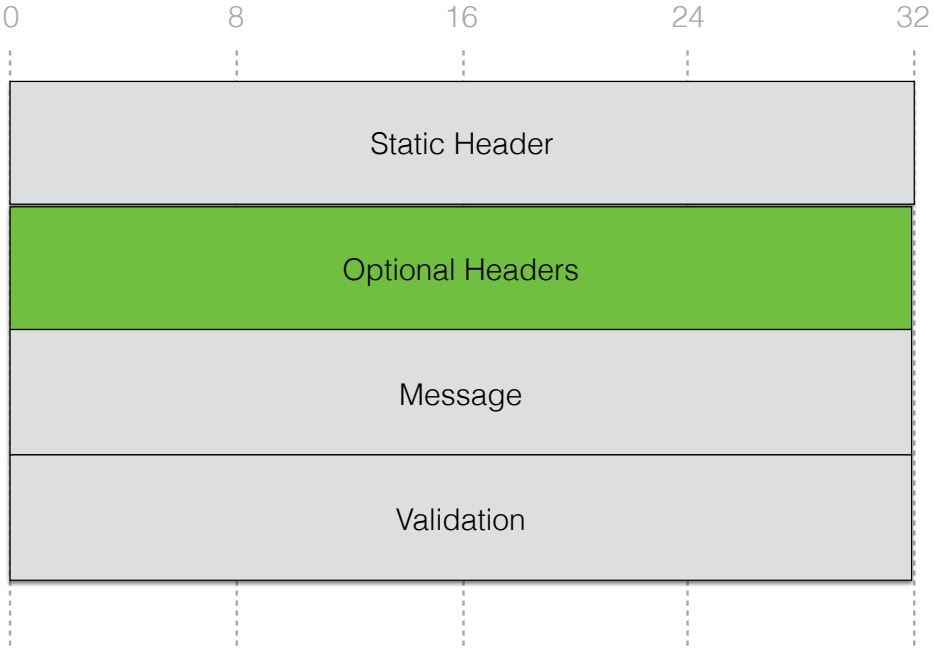
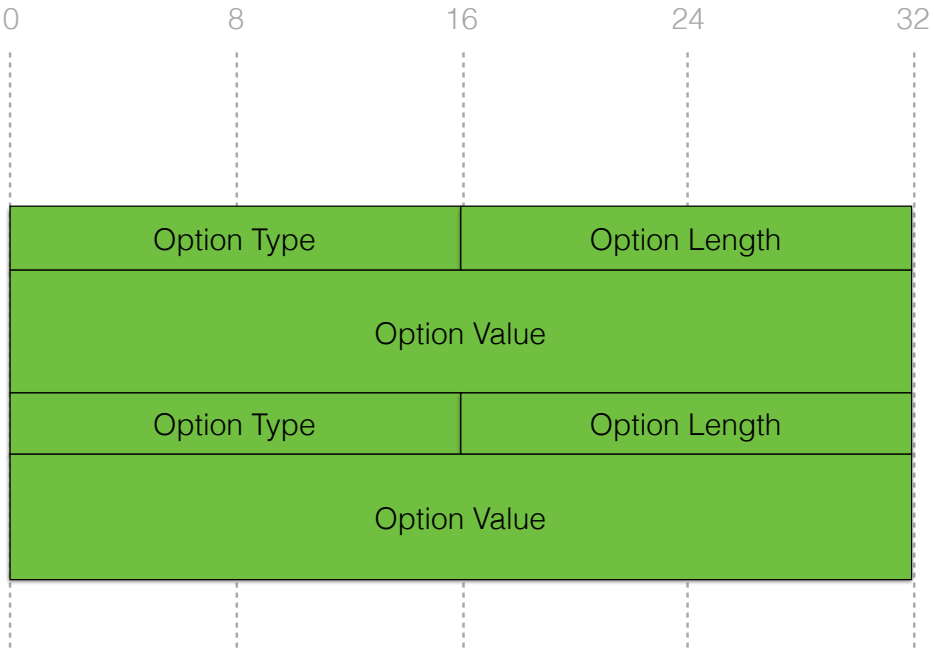


Packet Format



Optional Header



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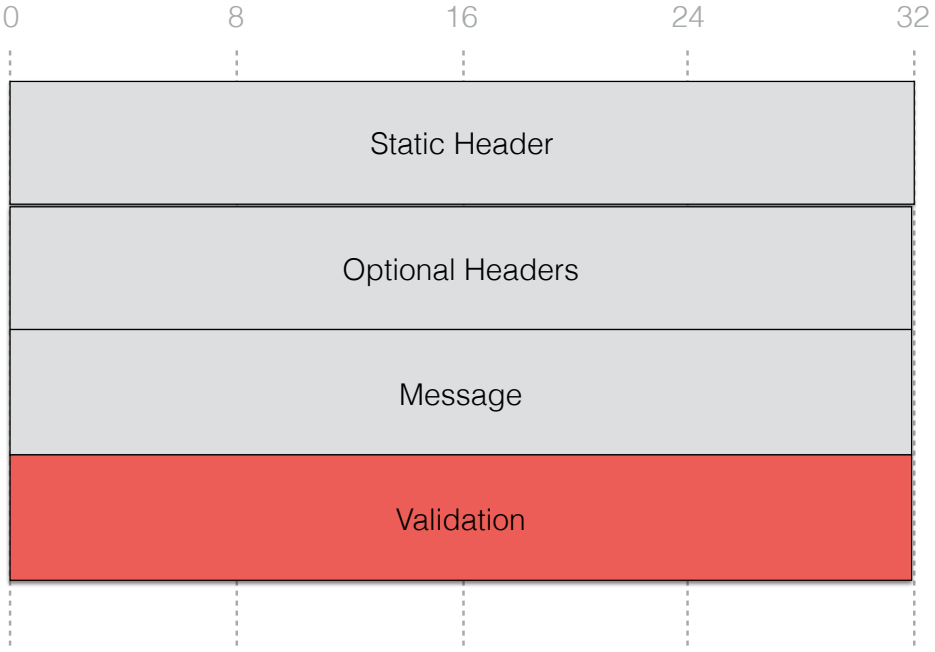
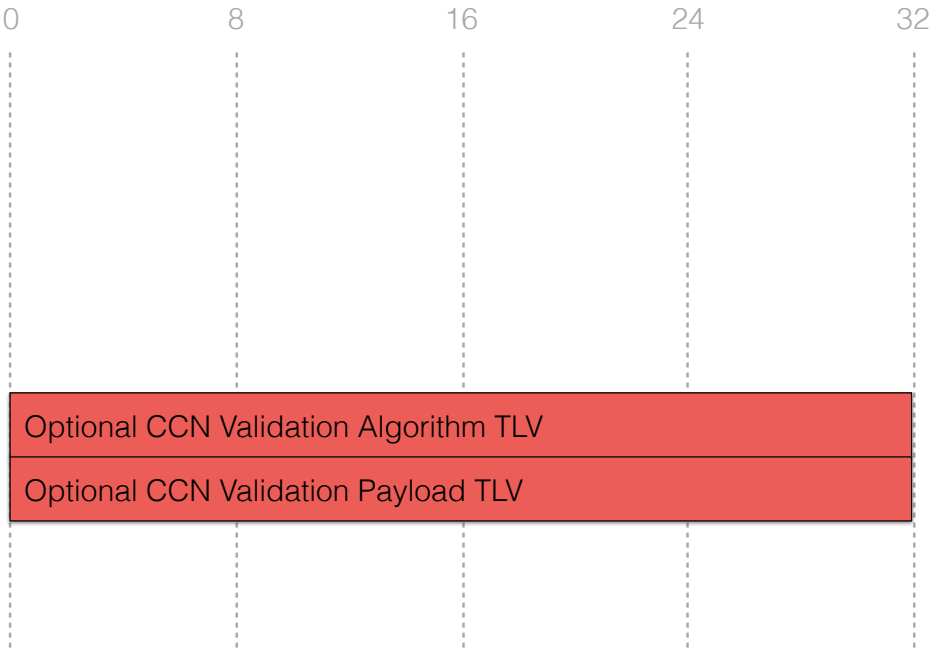


Validation



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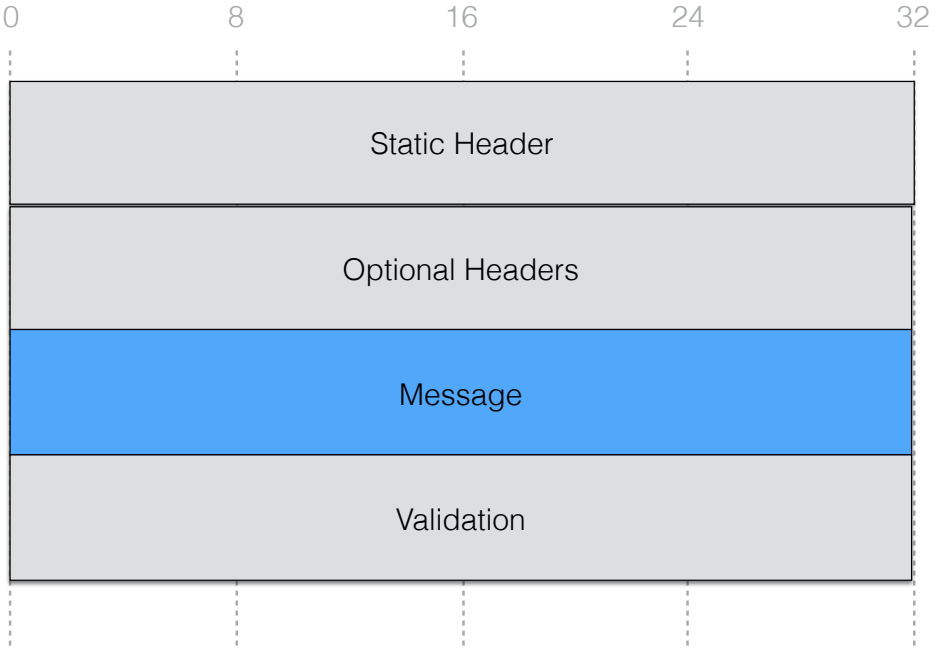
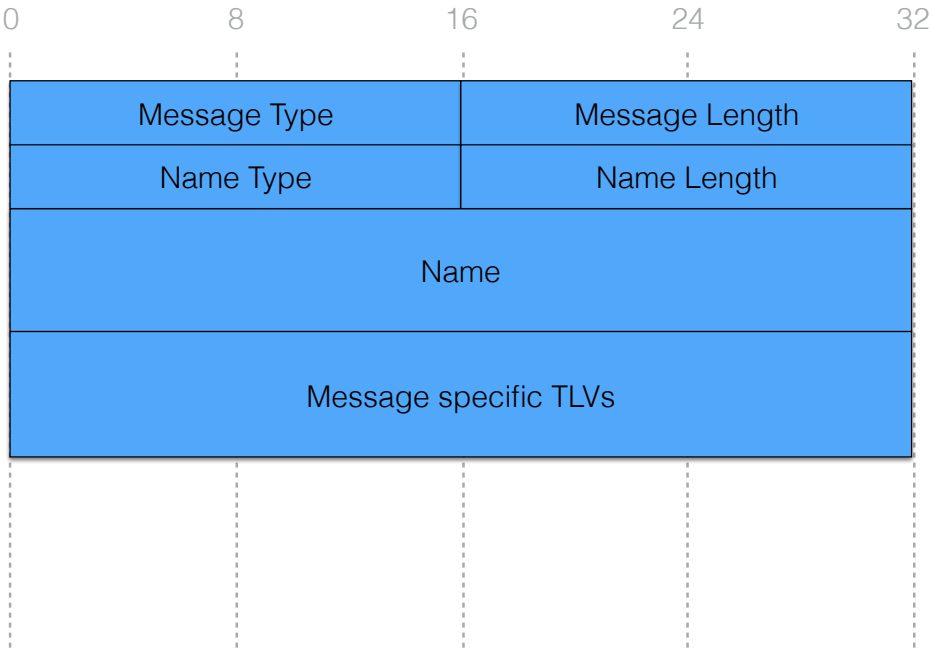
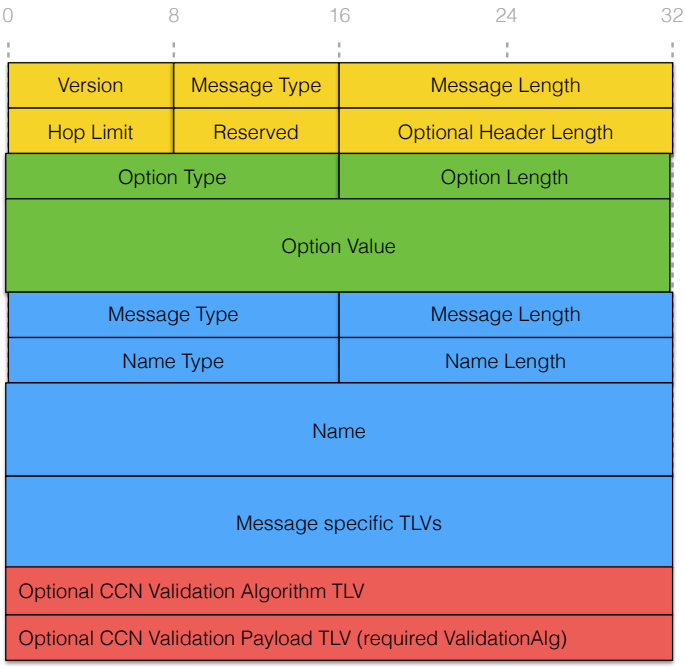


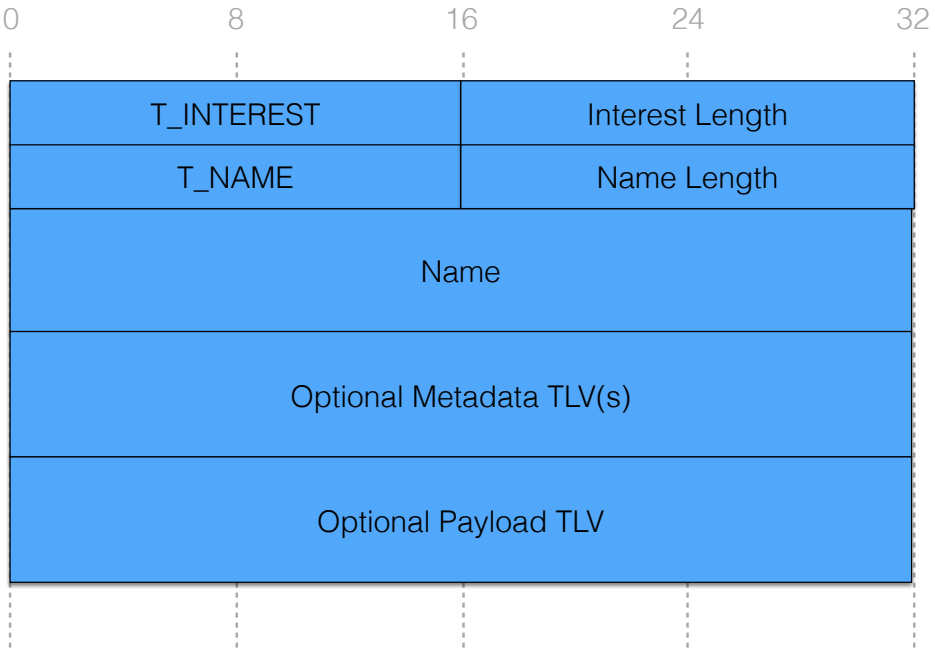
CCN Message



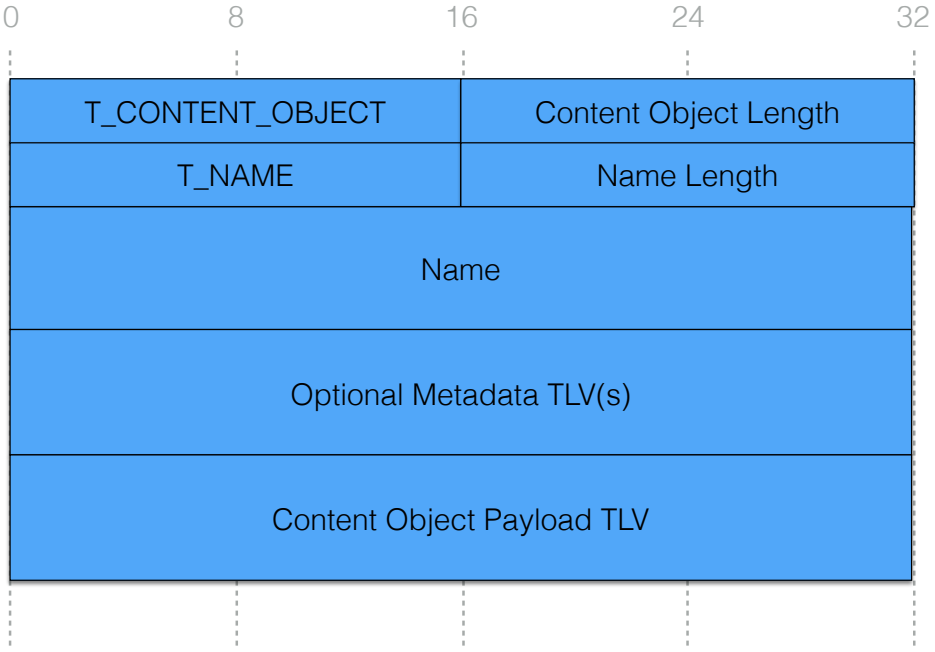
CCN Message



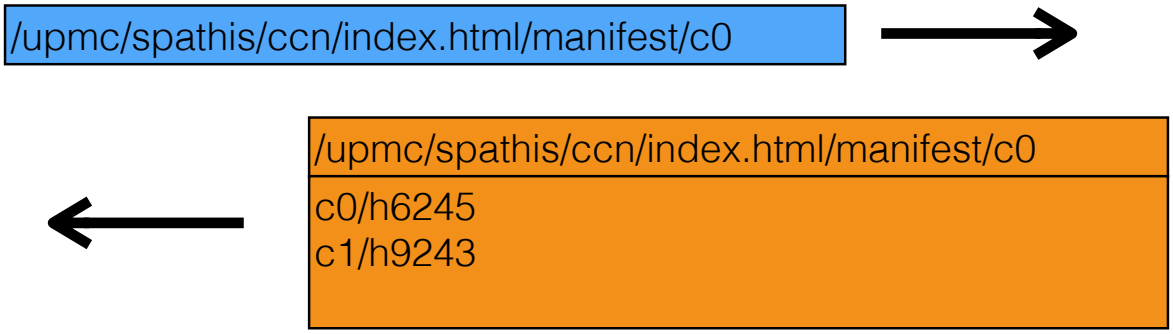
Interest Message



Content Object Message

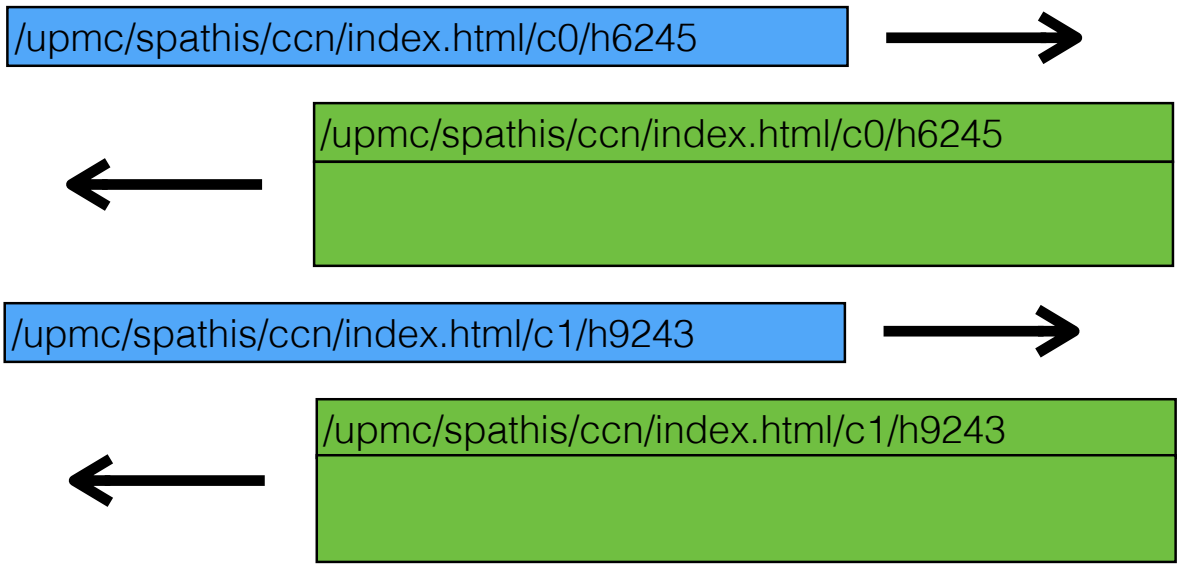


Quick Example Break



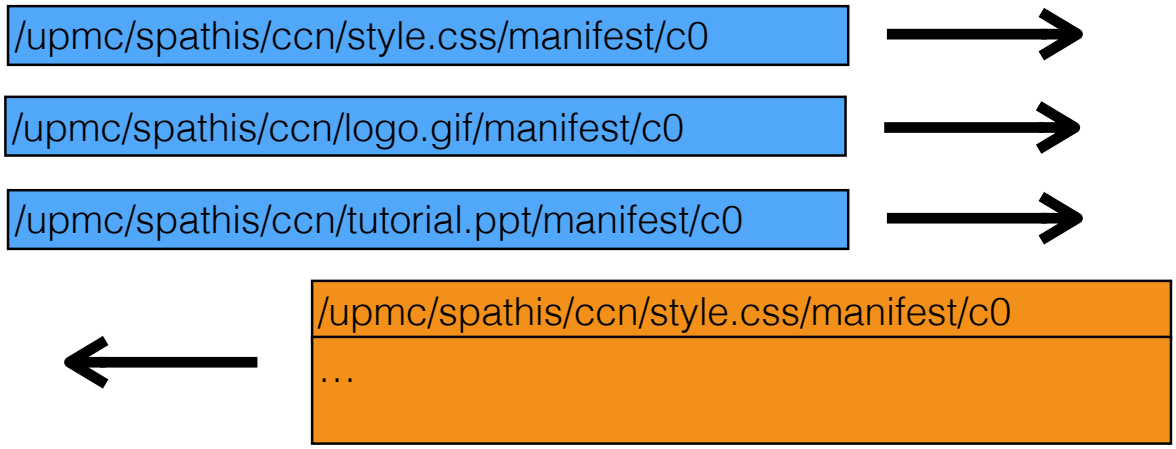
Request the list of chunks for the main webpage
Each chunk identified with a hash

Quick Example Break



Request each chunk using name and hash

Quick Example Break



Retrieve references

Securing Content

Content Packet = 〈 name, data, signature 〉

- Integrity & authenticity
  - Is it a complete, uncorrupted copy of what the publisher sent?
- Origin Authentication
  - Is the publisher one the receiver is willing to trust to supply this content?
- Correctness
  - Is this content an answer to the question the receiver asked.

Publishing and Verifying Content

$$M_{(N,C,P)} = \langle\ N,\ C,\ Sign_P(N,\ C)\ \rangle$$

- A content publisher
  - determines the name of its content (how it will be found)
  - generates a digital signature over that name and the content
- A content consumer, given N, must be able to retrieve
  - the content C, the authenticator $Sign_P(N, C)$
  - sufficient supporting information to determine what public key to use and where to find a copy

➡ User-friendly mechanisms to manage public and private keys

➡ Easy to deploy mechanisms to determine trust in keys and content

Content-based Security

- Security travels with the content
  - Content can be authenticated by any node (public key signatures)
  - Secure caching: can get content from anyone with a copy, and still authenticate it
  - Confidentiality: encrypt content for access control
- Move the security perimeter from the host to the application
  - Content decrypted only inside the target application
  - Use of encryption tailored to application needs
- Host protection
  - Harder to mount an attack against a host if you can't address packets to it
- Access control by policy routing

CCN Forwarder

- Routing

  Finding the path alternatives

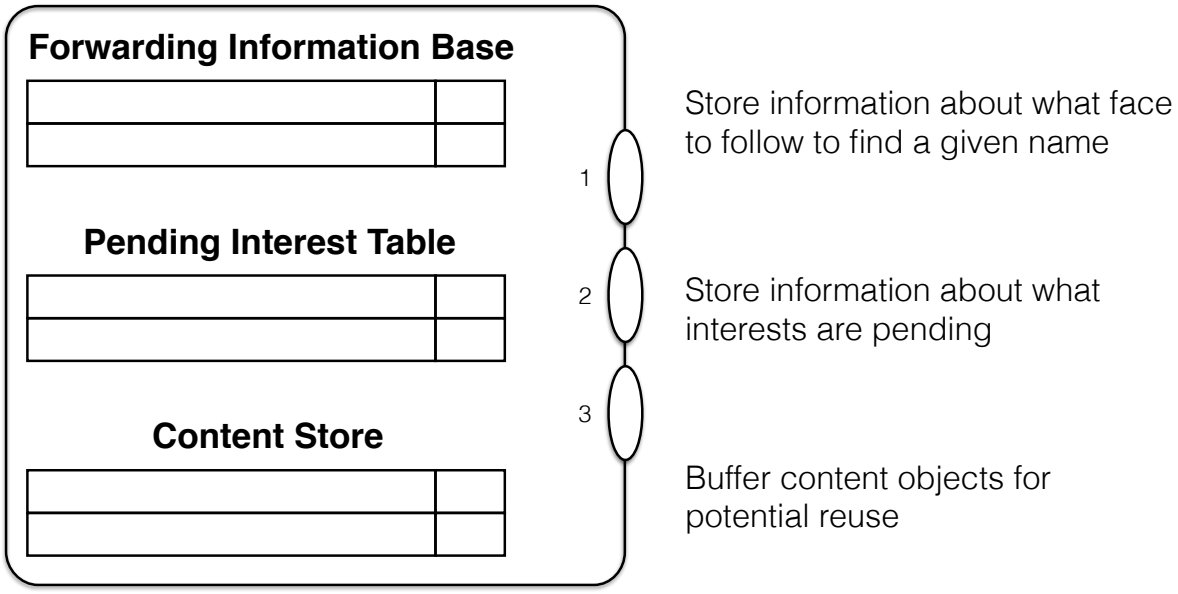
- Strategy

  How to use the alternatives

- Forwarding

  Processing a packet based on a strategy

CCN Forwarder



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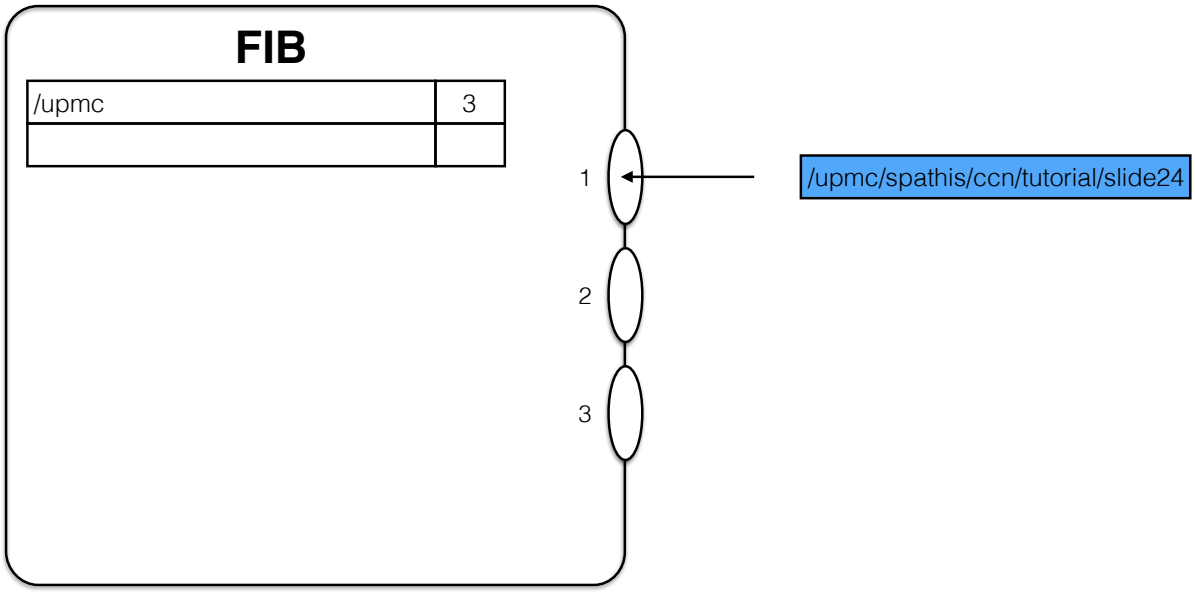

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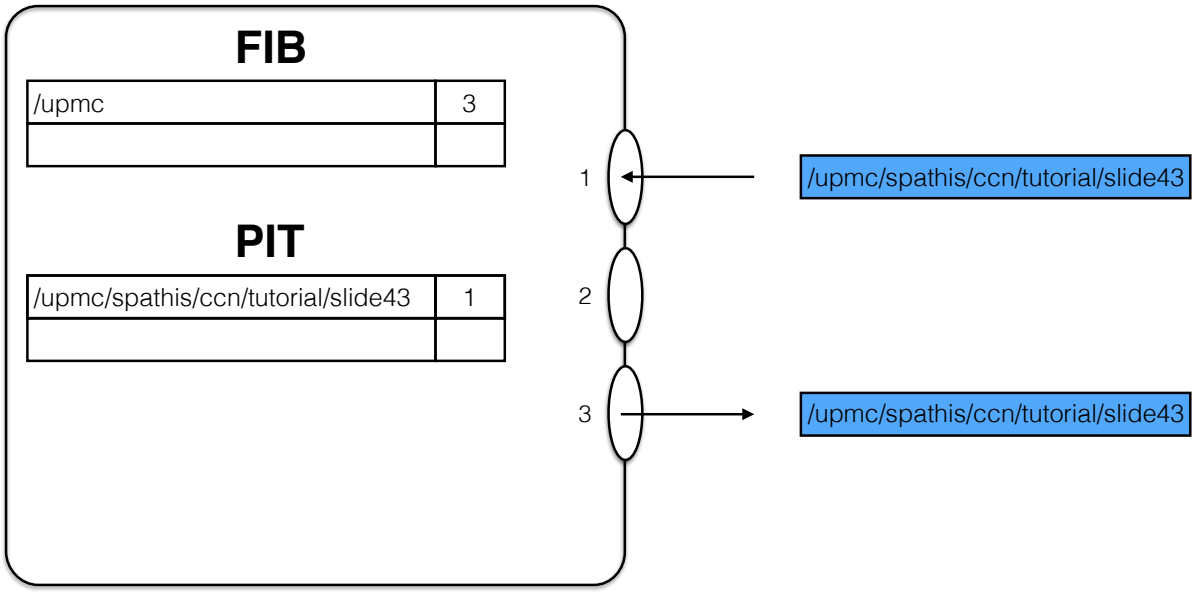

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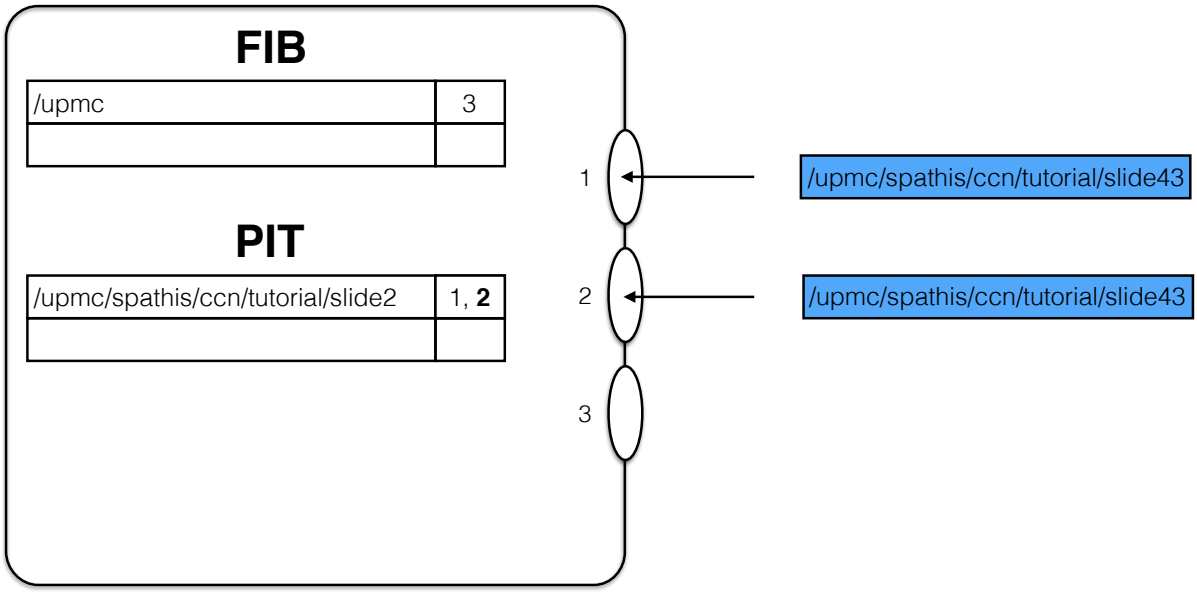

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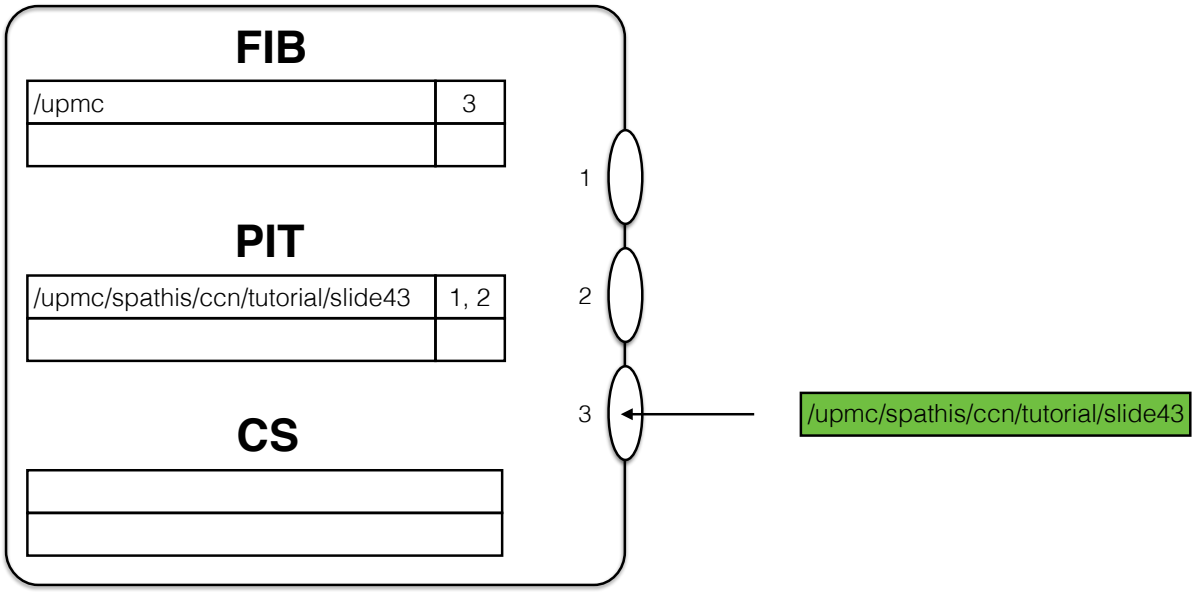

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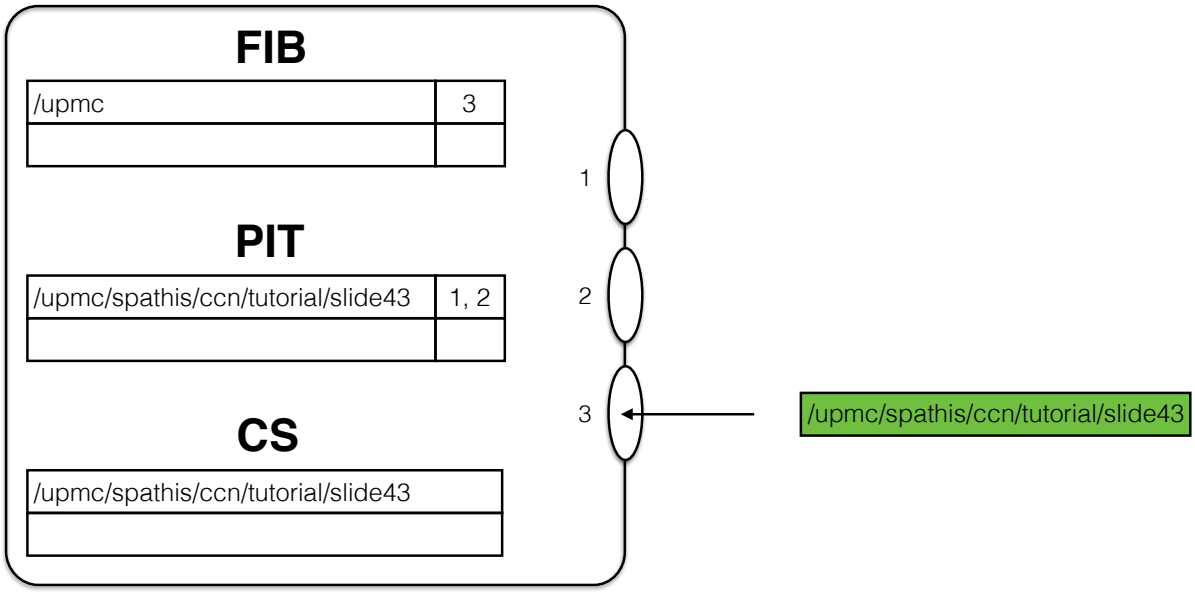

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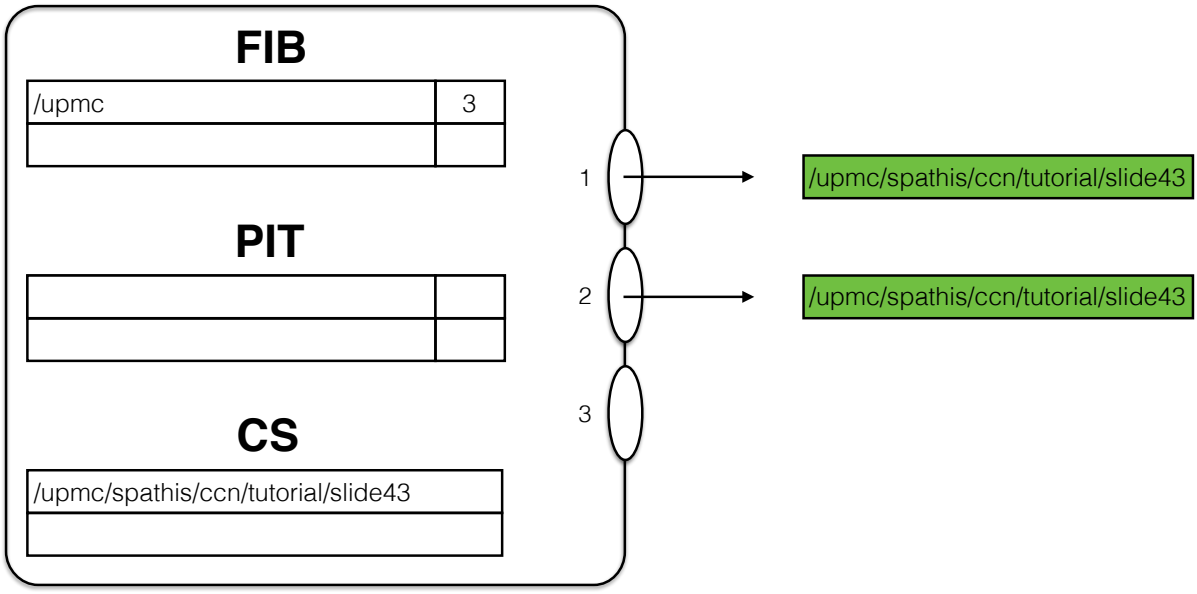

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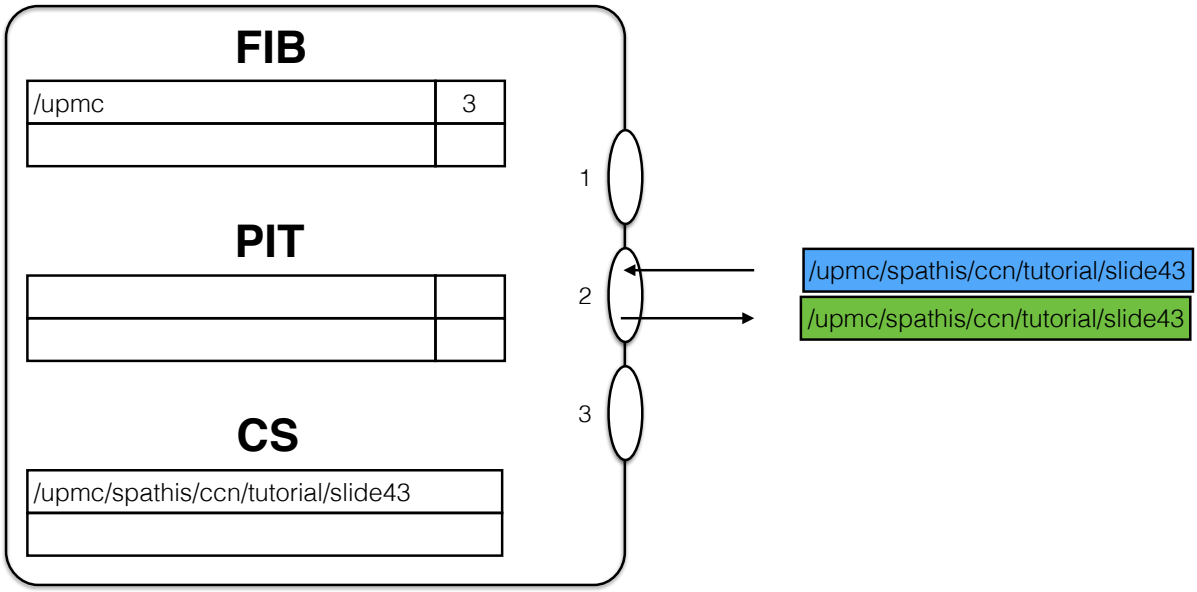
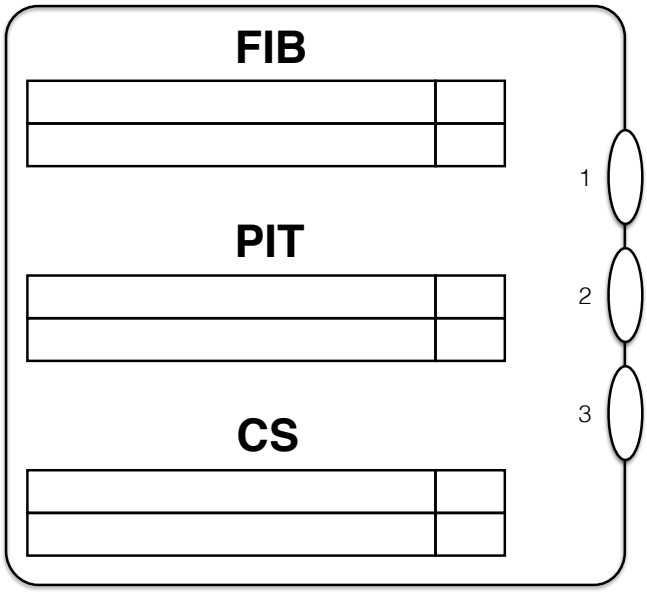


CCN Node Model

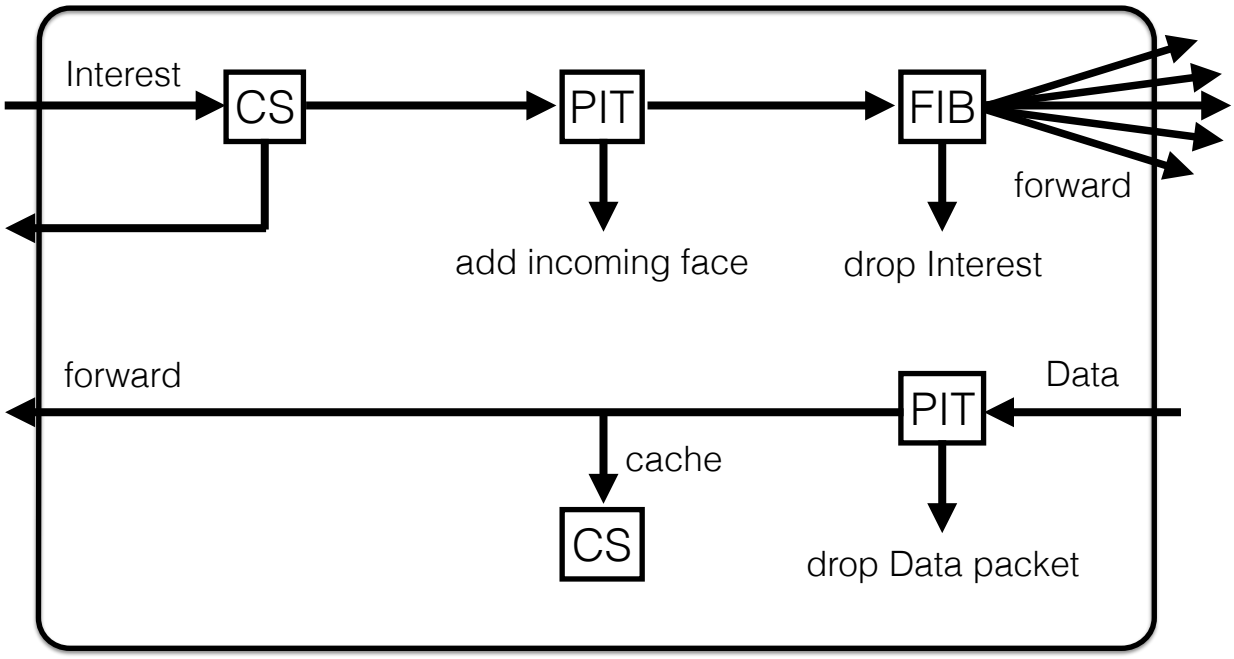


Longest matching prefix on names
Managed by external routing protocols

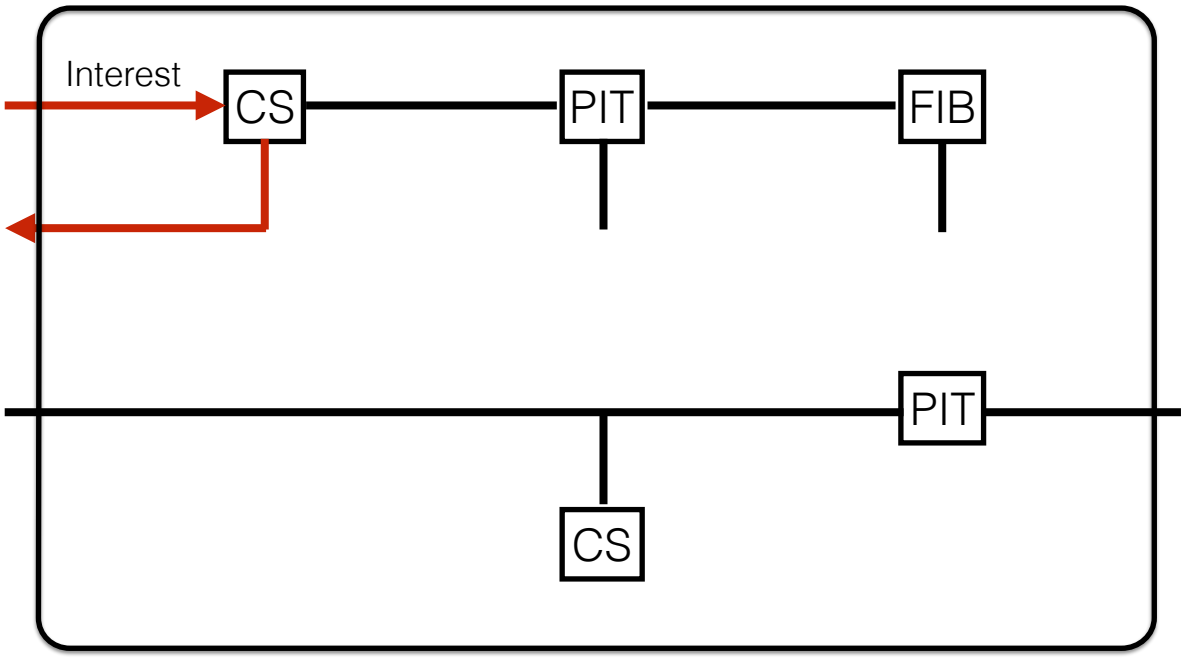
State for reverse-path forwarding

Long-term packet memory

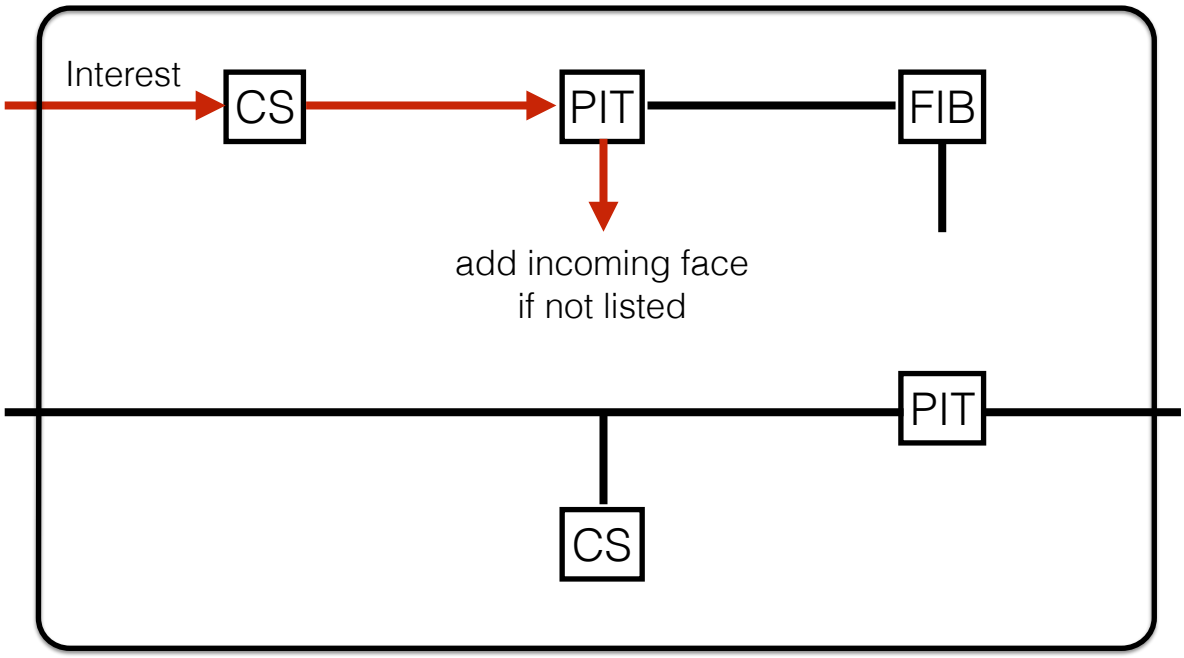
CCN Node Model



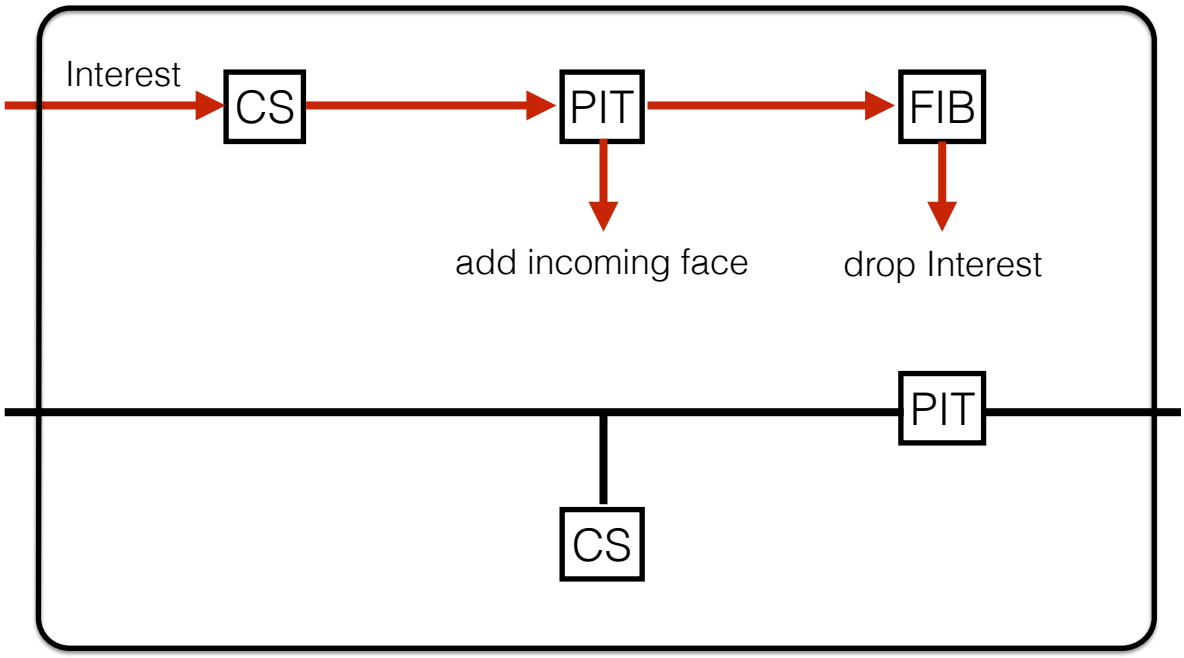
Interest satisfied by CS



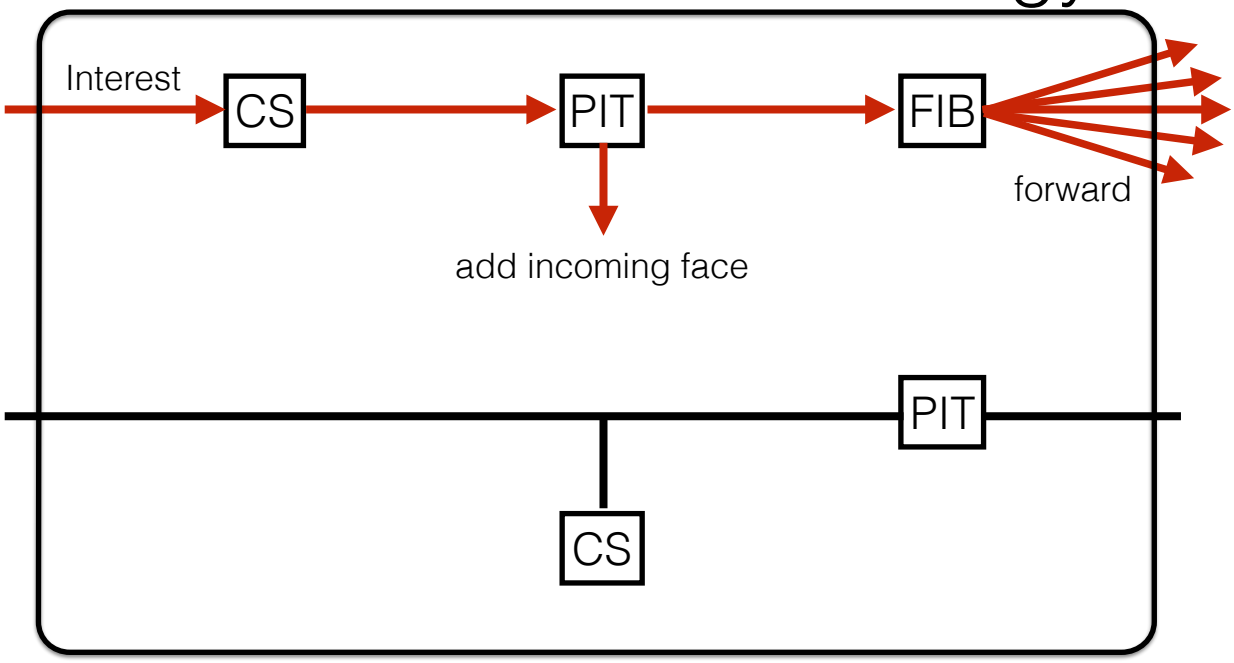
CS miss - Interest already in PIT



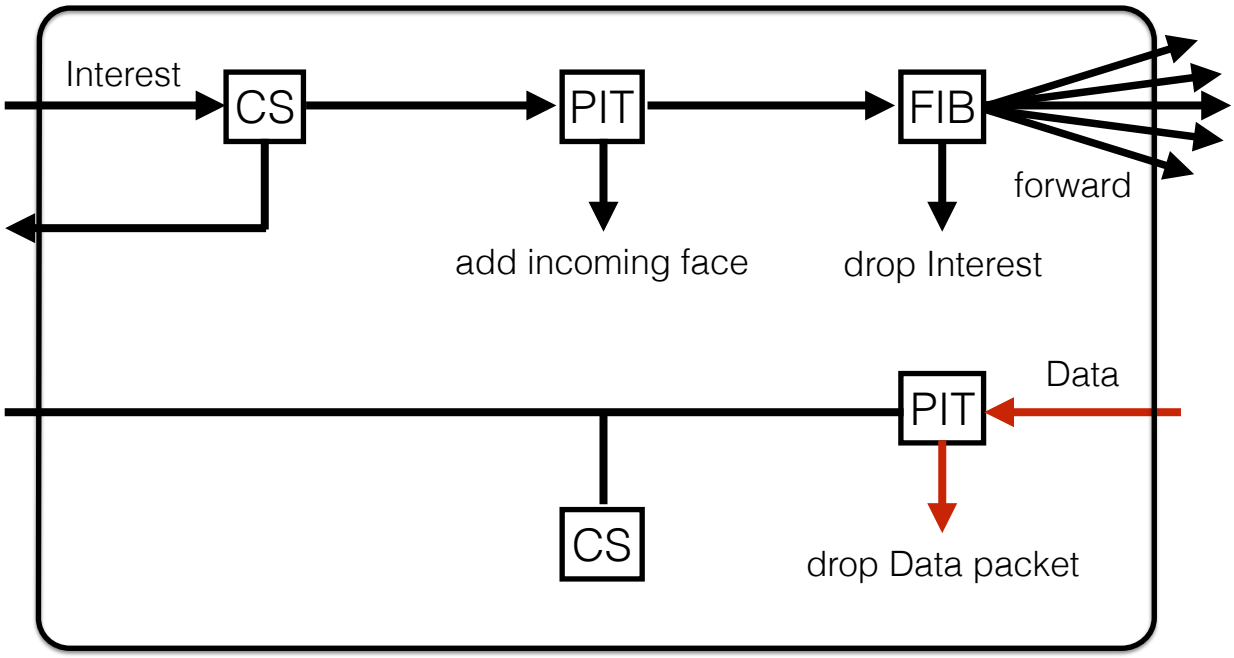
CS miss, PIT miss, no route in FIB for Interest



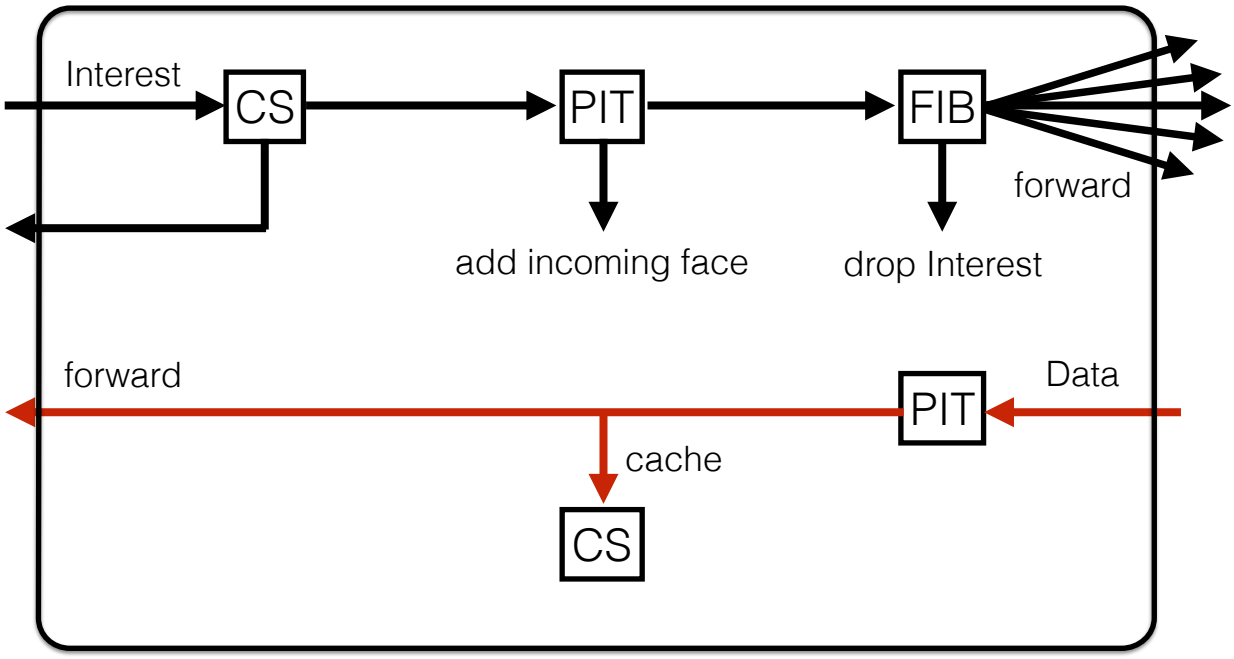
CS miss, PIT miss, route match in FIB - Forward via Strategy



PIT miss for Content



PIT match - Remove PIT entry, store copy in CS, reverse-path Forward



CCN Stateful Data Plane

- Named-based anycast and multicast delivery
  - Reverse-Path Forwarding
  - Scalable content distribution
  - Multipath forwarding
- Content Store
  - Offload sources for popular content
  - Retransmission buffer

CCN Data Plane Resilience

- CCN content delivery is a 2-step process:
  - Interest forwarding to set up state
  - Content traversal of interest path in reverse
- Content not forwarded w/out interests (i.e., request) for it
  - Multiple interests for same content are collapsed and one
  - copy of content per “interested” interface is returned
- Interest forwarding state eliminates looping, allows exploitation of topological redundancies and multipath forwarding
- Content packets measure quality of selected (interest) paths
  - Forwarding plane can incorporate congestion and fault mitigation into path decisions
  - Content caching increases availability & mitigates DoS attacks

CCN Routing

- Multiple copies of Content Objects
  - Opportunist replication, caching, or migration
- How to route towards one or all copies of the same object?
  - Source does not know any instances
  - Source knows all instances
  - In-between: Designated representative

Remember Multicast

- Flood and Prune (PIM-DM)
  - Reach all possible destinations, prune all except instances
- Link-state Multicast (MOSPF)
  - Topology is known so the location of the instances
  - Compute the source-tree to all instances
- Core-based Trees (aka PIM-SM)
  - Rendez-vous point in-between the source and the instances
  - Compute the tree rooted at the RV point

CCN Current Routing Proposals

- Network topology and location of all instances known
  - Named-data Link State Routing Protocol (NLSR)
- w/o knowing all, flooding, or predefined core

Named Link-State Routing NLSR Protocol (ICN'13)

- Naming routers and routing process

```
/<network>/<site>/<router>/NLSR
```

- Link-state advertisements
  - Adjacency LSAs (Neighbor 1 Name, Link 1 Cost, ...)

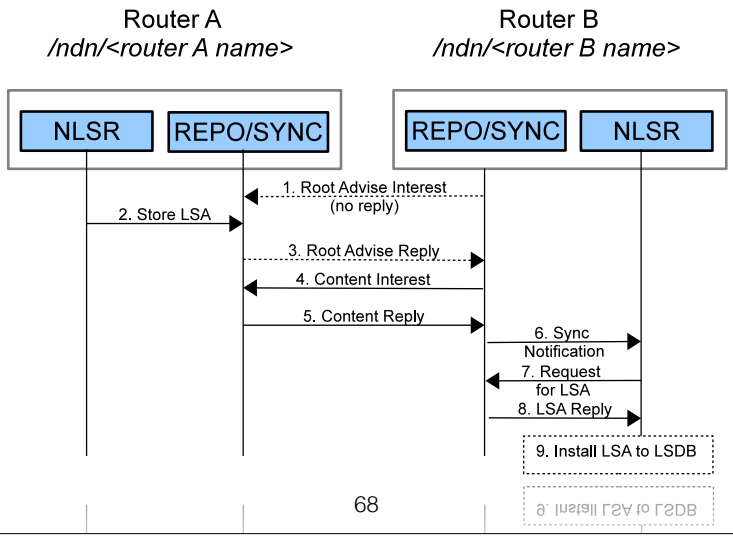
```
/<LSA-prefix> /<site>/<router>/LsType.1/<version>
```

  - Prefix LSAs (isValid, name prefix)

```
/<LSA-prefix>/<site> /<router>/LsType.2/LsId.<ID>/
                     <version>
```

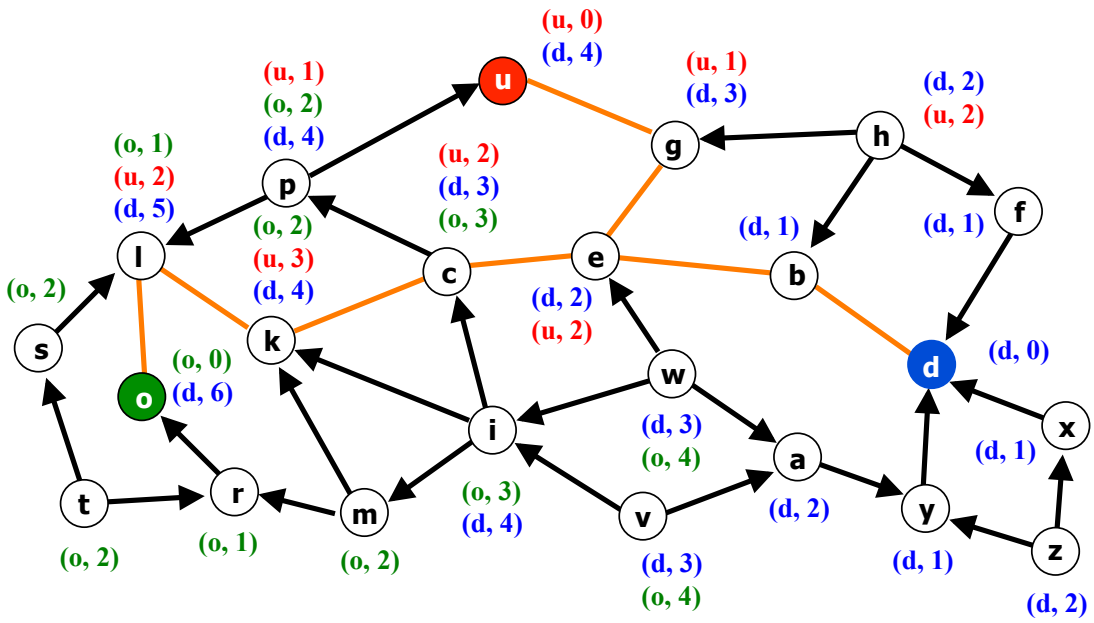

LSDB Synchronization

- Use of CCNx synchronization protocol
  - LSDB seen as a CCNx repository, collections of named data
  - Detection of inconsistencies through periodic exchanges of LSDB hashes



Distance-based Content Routing DCR (ICN'14)

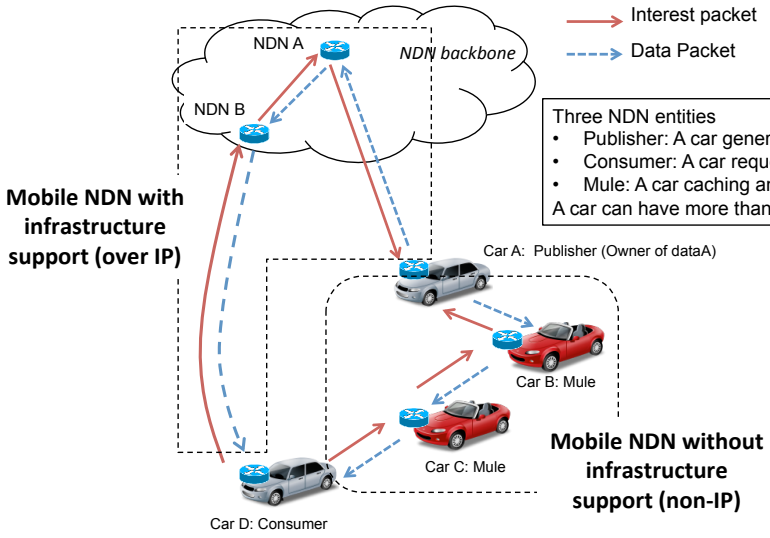
- Establish a lexicographic ordering of distances to multi-instantiated destination
- The name of a router "speaking for" a destination instance (called anchor) is an attribute used in the ordering
- Routers choose what to share with their peers (e.g., "the best distance according to the lexicographic ordering")
- Lexicographic ordering among instances defines an instance where a DAG spanning all instances is rooted



- Lexicographic ordering based on hop count to instance, ID of instance's anchor , sequence number from anchor
- Route to some *nearest* instances w/o knowing all, flooding, or predefined core

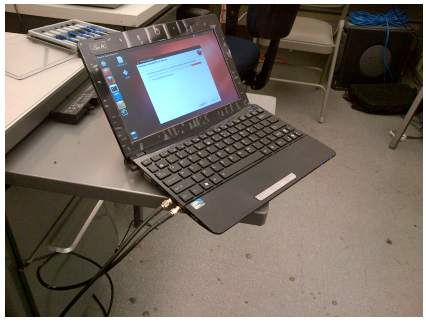
Vehicular Named Data Networking

Implemented a Linux-based NDN daemon, with enhancement to WiFi broadcast support



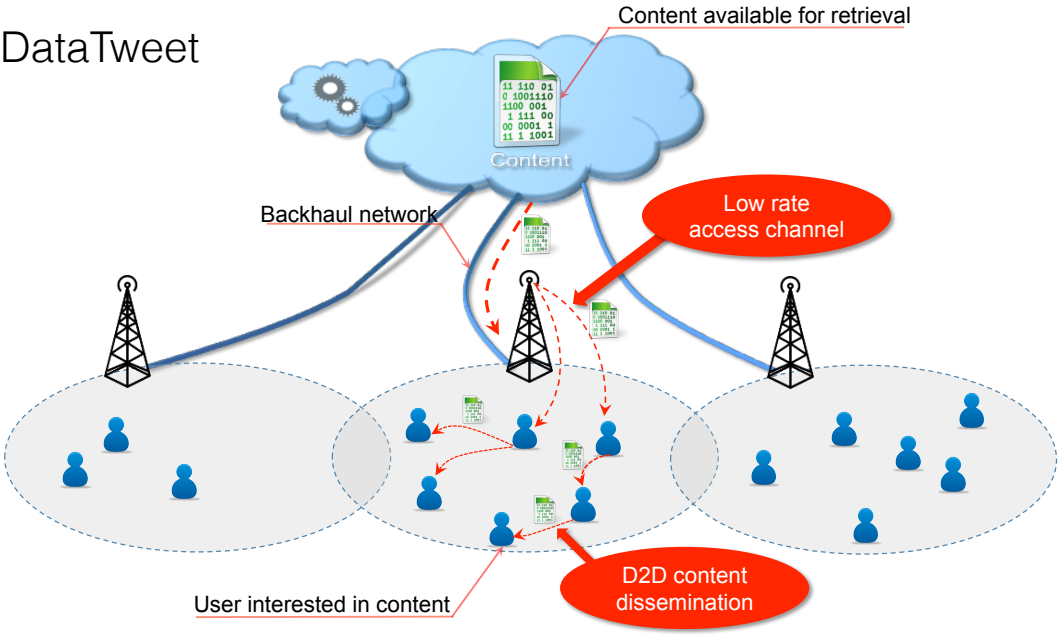
Three NDN entities
- Publisher: A car generating data
- Consumer: A car requesting data
- Mule: A car caching and forwarding data

A car can have more than one role at a time.



Content Centricity in Constrained Cellular-Assisted D2D Communications

ANR DataTweet



Key Issues

- Define Autonomous Systems for CCN, incorporate routing policies and an inter-domain trust model
- Applying CCN to solve real networking problems
  - Internet is already information-centric
    - youtube, netflix, amazon, facebook
    - new generations of applications
  - Solving info distribution problems via IP point-to-point communication, as we do today, is complex & error-prone

Analogy with TCP/IP in the 80s

- Promising new technology
- Largely unknown outside its small community
- Federal funding led TCP/IP to its success
  - BSD development, NSFnet
  - Various research projects over Internet
- A number of problems exposed and resolved through larger scale experimentation
  - DNS development
  - Congestion control
  - Evolution of the routing system
  - …

Takeaways

- Recognizing the right communication abstraction
- CCN focuses on retrieving data rather than conceptualizing communication between hosts
- Security, delivery efficiency, mobility and disruption tolerance than TCP/IP
- CCNx, NDN: Tools for experimenting new apps in emerging environments