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# Research Trends on Information-Centric Networks

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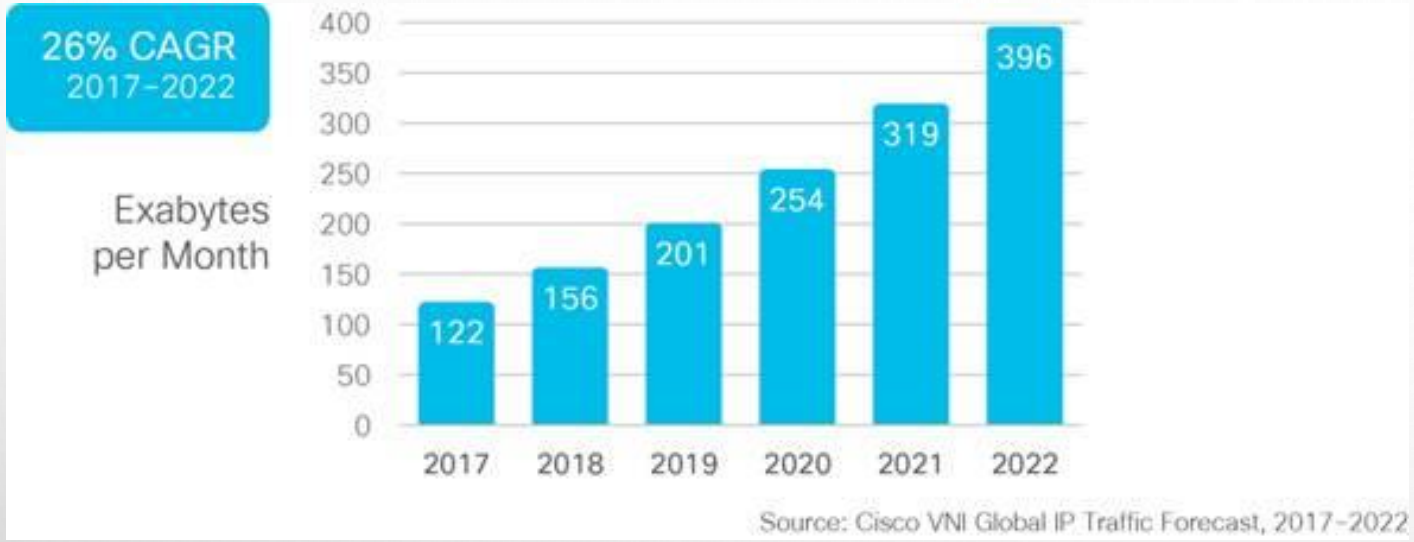
# OUTLINE

1. Backgrounds
2. History
3. CCN/NDN Overviews
4. NDN Congestion Control
5. NDN Routing
6. Other Topics and Future Trends
7. References

# 1. BACKGROUNDS (1)

- Internet traffic increasing and various types of terminals/networks introducing
- Especially,
  - On demand video retrieval such as YouTube, Hulu, Netflix with 4K or 8K resolution
  - Increasing mobile terminals, increasing bandwidth with 5G mobile network
- CISCO systems provide forecasts of global IP traffic growth for mobile and fixed networks [1].
  - Total global IP traffic will reach 396 exabytes/mo in 2022. In 2017, 122 EB/mo.
  - Global IP traffic will increase threefold over the next 5 years. 26 % annual growth rate.
  - Busy hour Internet traffic is growing more rapidly than average Internet traffic. 4.8 times.

# 1. BACKGROUNDS (2)

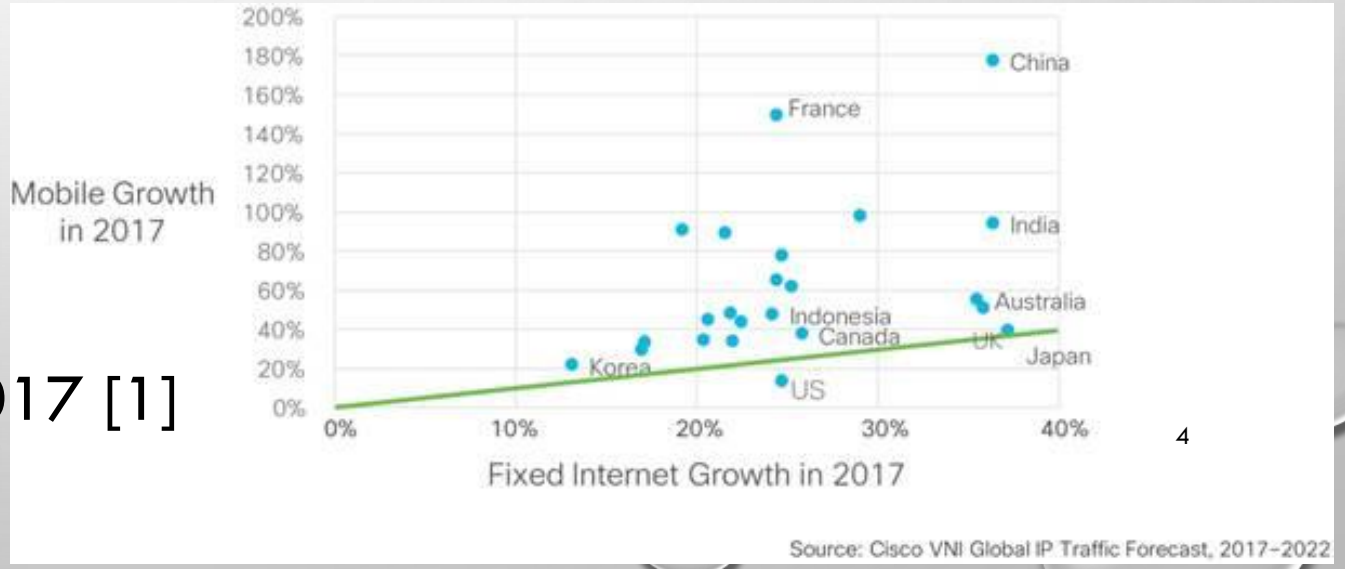



- 396 EB/mo = 1.222 Peta b/s

= 1222 Tb/s

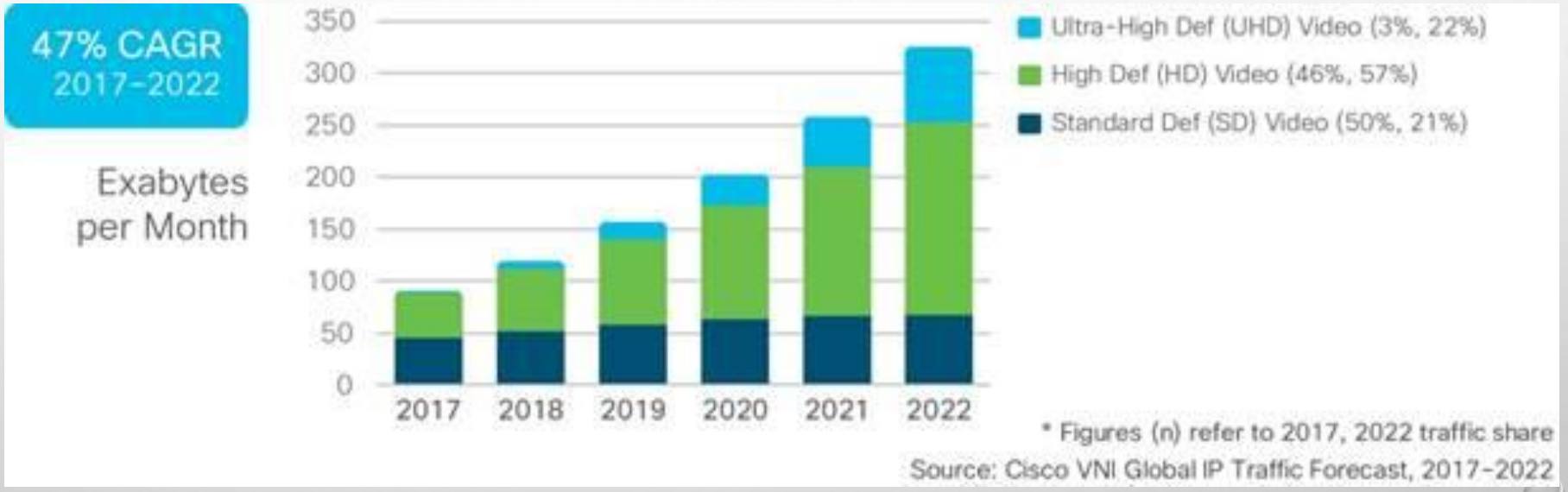
CAGR: Compound Annual Growth Rate

- increase of devices in 2017 [1]



# 1. BACKGROUNDS (3)

- CISCO forecast says that IP video traffic will be 82 % of all IP traffic by 2022, up from 75 % in 2017 [1].




- UHD (or 4K) video will account for 22 percent of global IP Video traffic by 2022. UHD as a percentage of IP VoD traffic will be higher at 35 percent by 2022.

# 1. BACKGROUNDS (4)

- How to decrease on demand video retrieval traffic:
- Current approach is Content Delivery Network (CDN)
  - Introduce multiple cache servers.
  - Preload popular video files into cache servers.
  - When such video is requested, select a cache server, near to the client or with light load.
- How to locate a cache server: with help of DNS server translating URL to IP address of appropriate cache server
- Issues of CDN
  - Only preselected videos are distributed over cache servers.
  - It is difficult to locate cache servers and to distribute videos optimally.

# 1. BACKGROUNDS (5)

- Information-Centric Network (ICN) or Content-Centric Network (CCN)
  - Completely new approach (reconstruct Internet architecture).
  - Not use IP address of video server (or cache server), but use the name of content.
  - All routers work as cache servers.
  - All content can be cached.

- Proposed by Van Jacobson in 2006 in Google Tech Talk [2].

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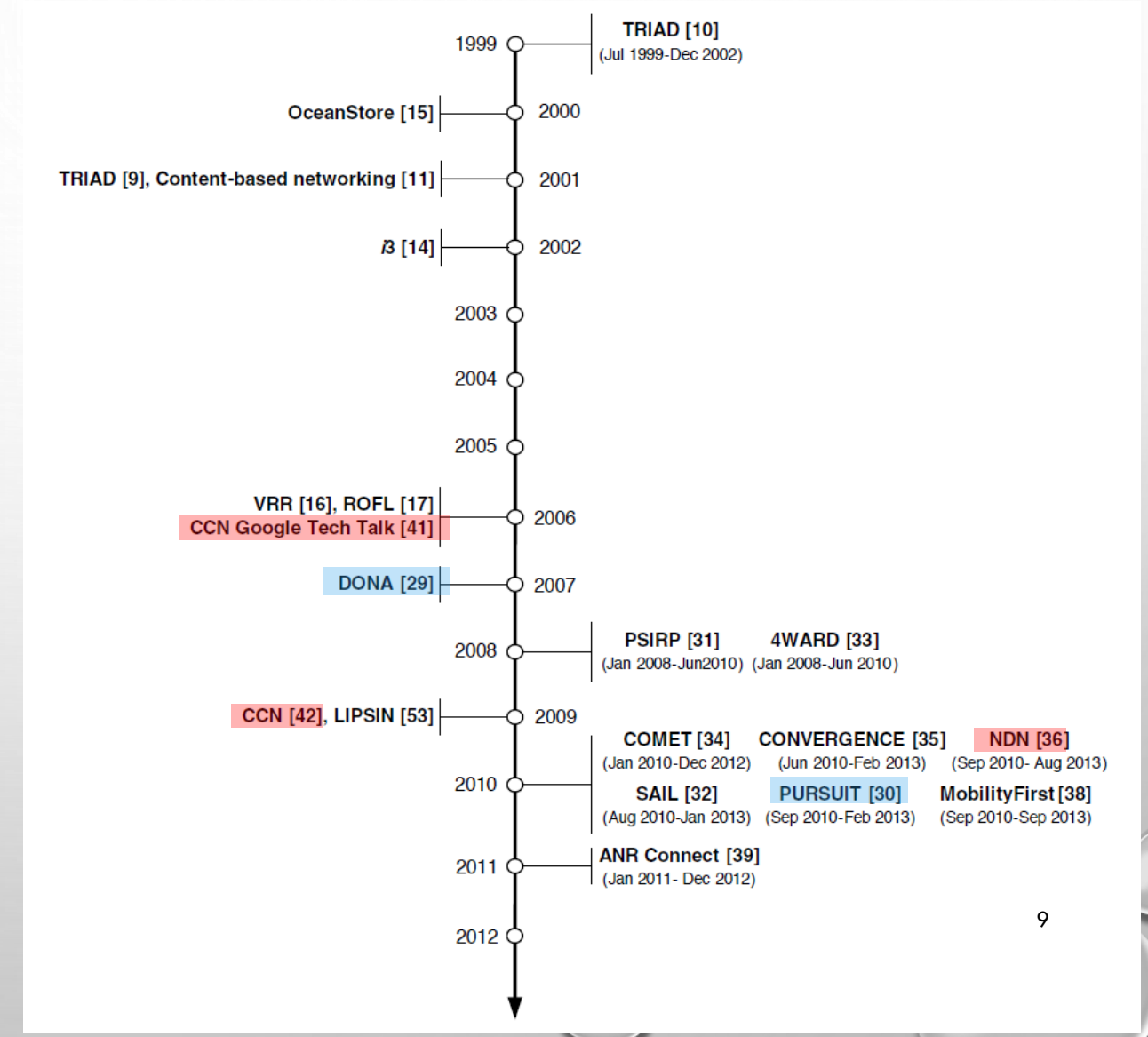
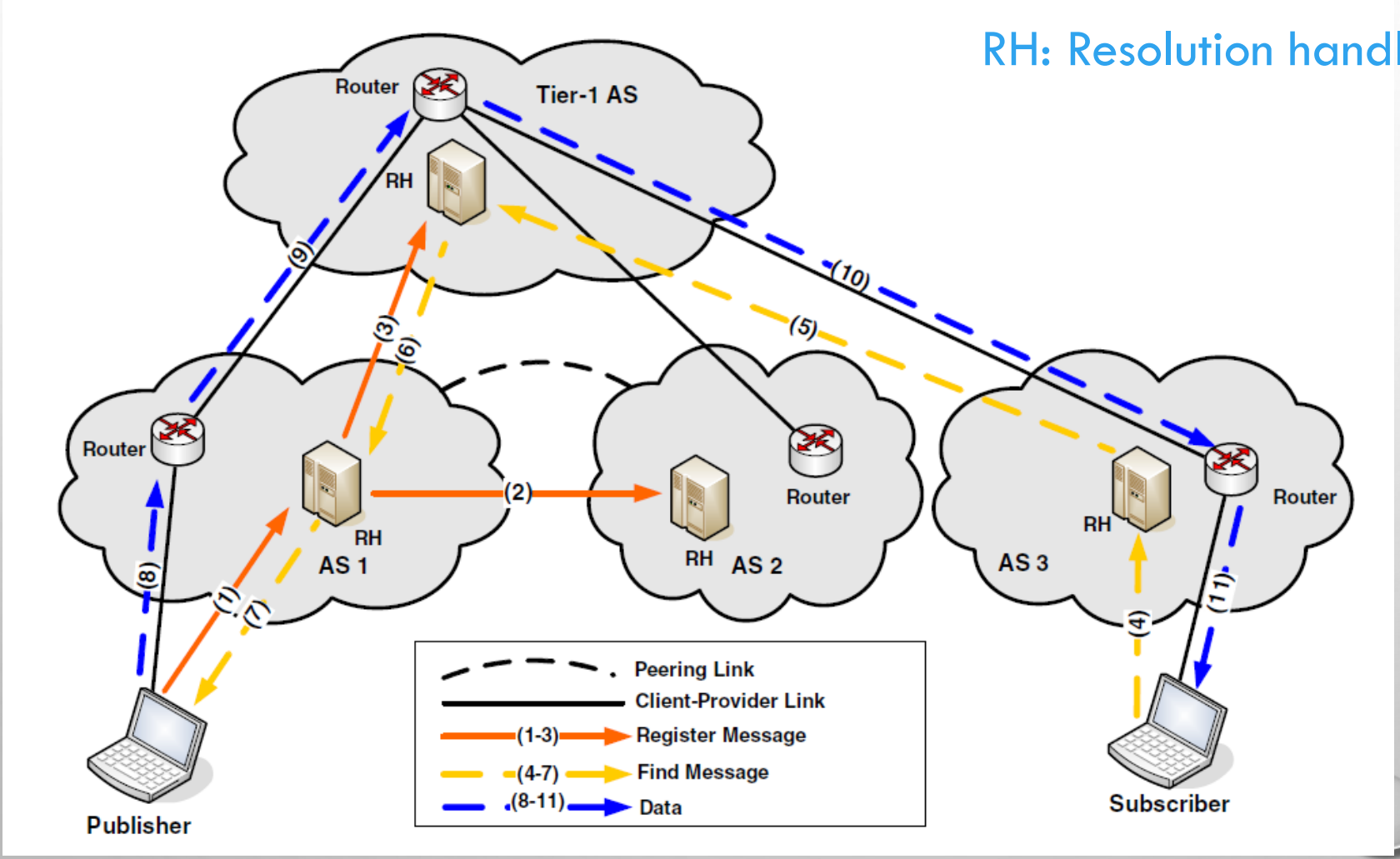
# 2. HISTORY (1)

- Actively studied since late 2000's. Several projects in EU and USA [3].
- 2006: Jacobson's talk
- 2007-2011: Many proposals
  - DONA (Data Oriented Network Architecture) from UC Berkeley
  - CCN (Content Centric Networking) and NDN (Named Data Networking) from PARC (Jacobson)
  - PURSUIT (Publish Subscribe Internet Technology) from an EU project



# 2. HISTORY(2)

- DONA (Data Oriented Network Architecture) [3]

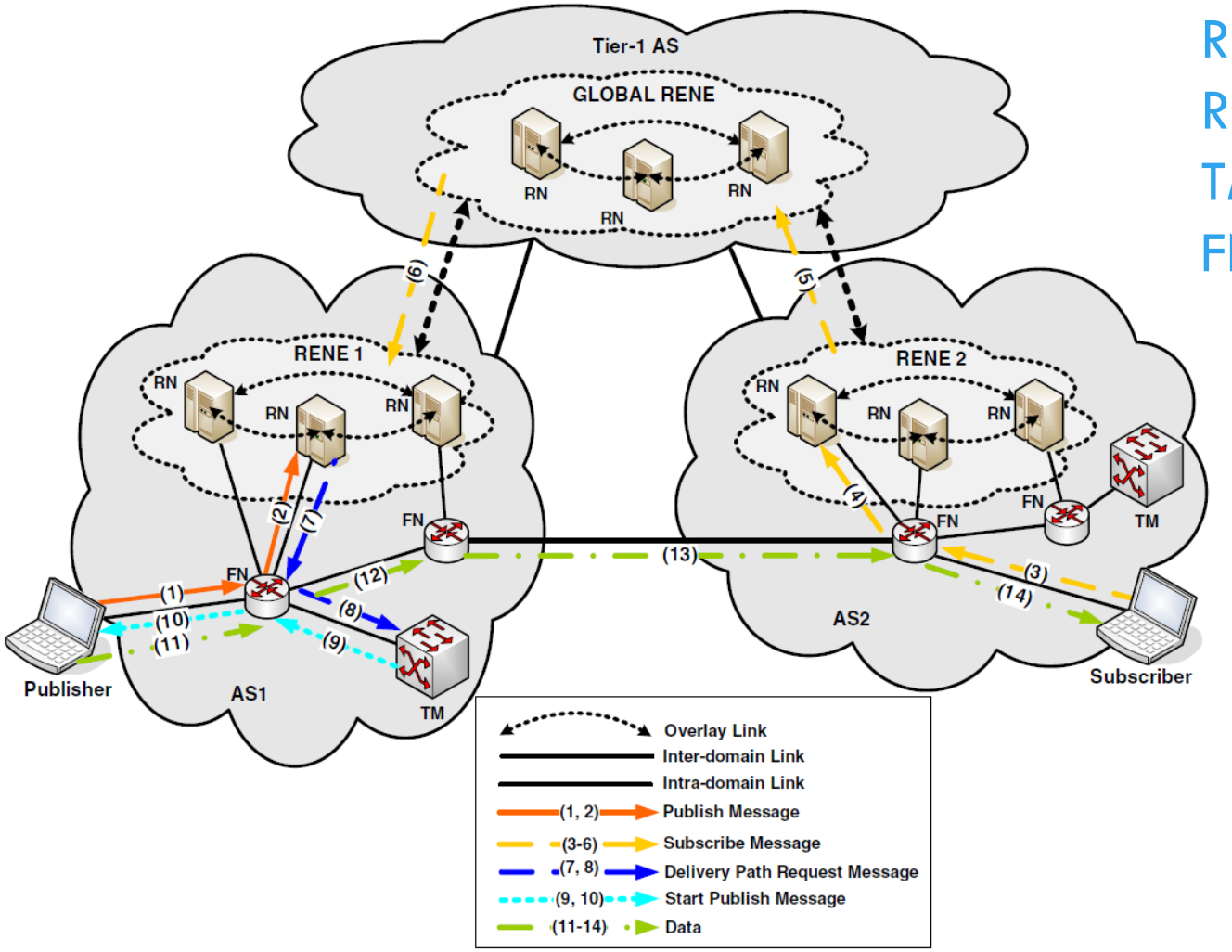



RH: Resolution handler

- Find/Data messages
- Data may be directly sent to subscriber, or via RHs.
- RH may cache Data.

# 2. HISTORY(3)

- PURSUIT (Publish Subscribe Internet Technology) [3]

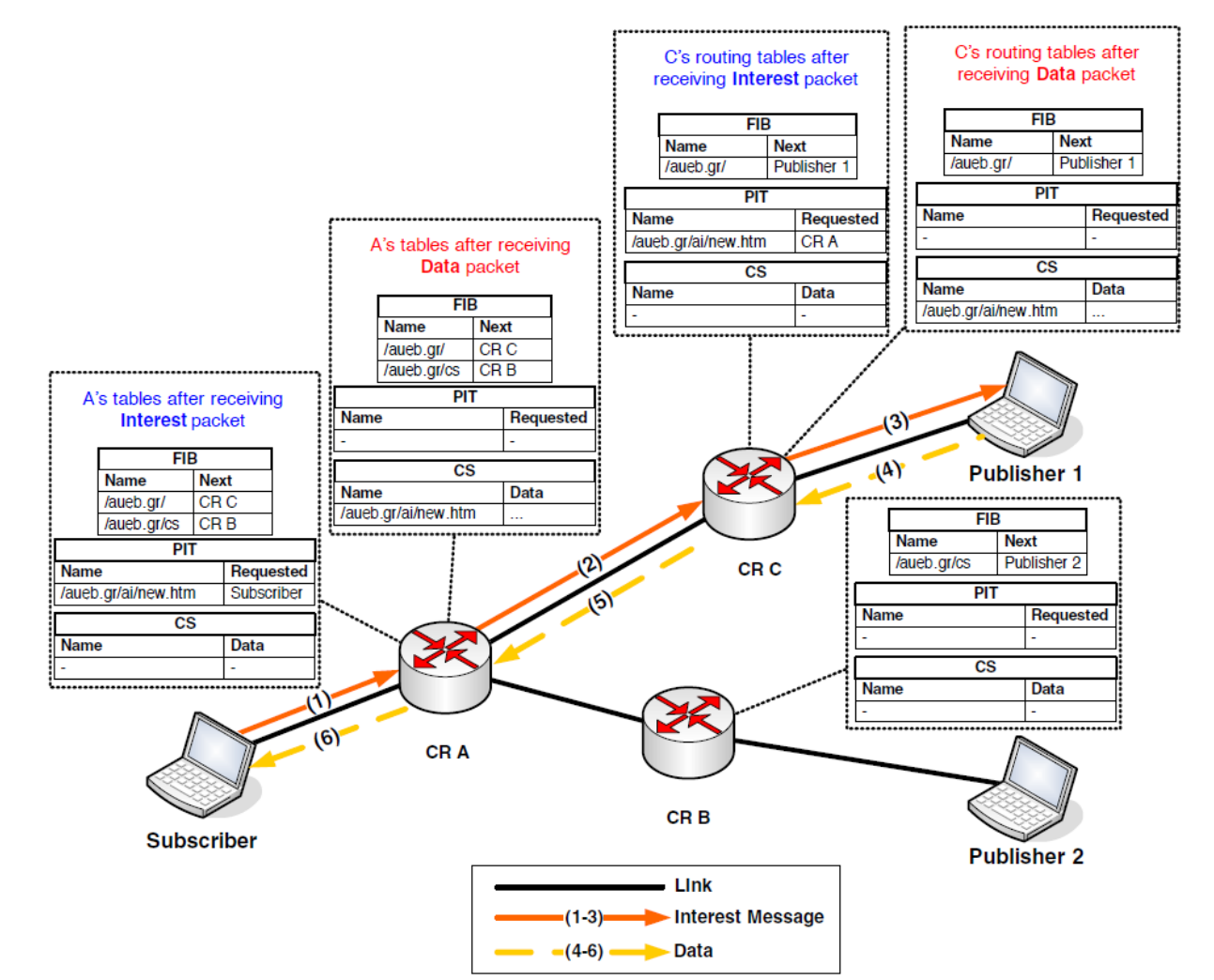



RN: Rendezvous node
RENE: Rendezvous network
TM: Topology manager
FN: Forwarding node

- Publish message
- Subscribe/Data messages
- Data is sent via FN.
- FN path is managed by TM.
- FNs cache Data.

# 2. HISTORY(4)

- NDN (Named Data Networking) [3]




CR: Content router

- Interest/Data messages
- Data is sent in the reverse path of Interest message.
- CRs cache Data.

- Very simple architecture.
- Can be realized without IP.
- Many studies focus on it.

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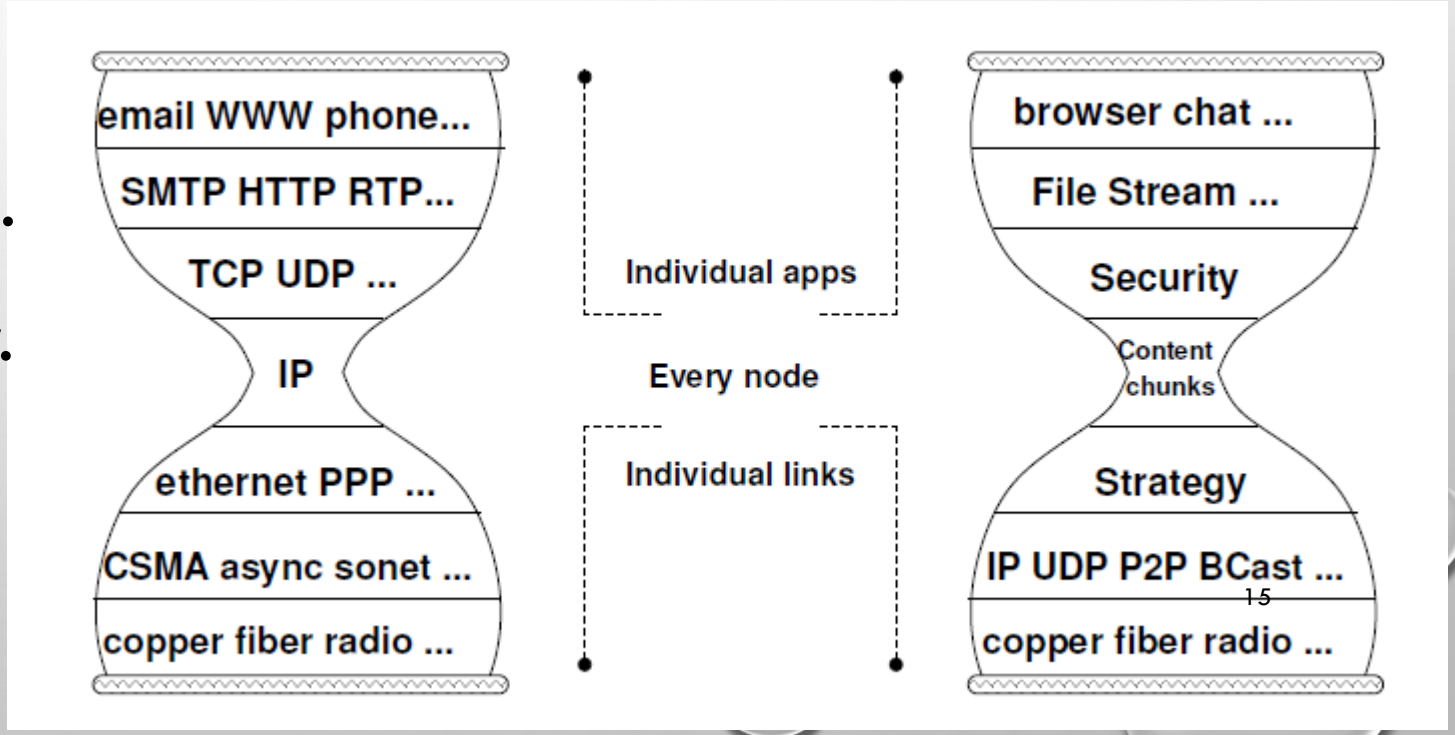
# 3. CCN/NDN OVERVIEWS (1) INTRODUCTION (1)

- Jacobson published a paper on Named Data Networking [4].
- "People value the Internet for *what* content it contains, but communication is still in terms of *where*."
- Issues:

- **Availability**: Fast, reliable content access requires awkward, pre-planned, application-specific mechanisms like CDNs and P2P networks, and/or imposes excessive bandwidth costs.
- **Security**: Trust in content is easily misplaced, relying on untrustworthy location and connection information.
- **Location-dependence**: Mapping content to host locations complicates configuration as well as implementation of network services.

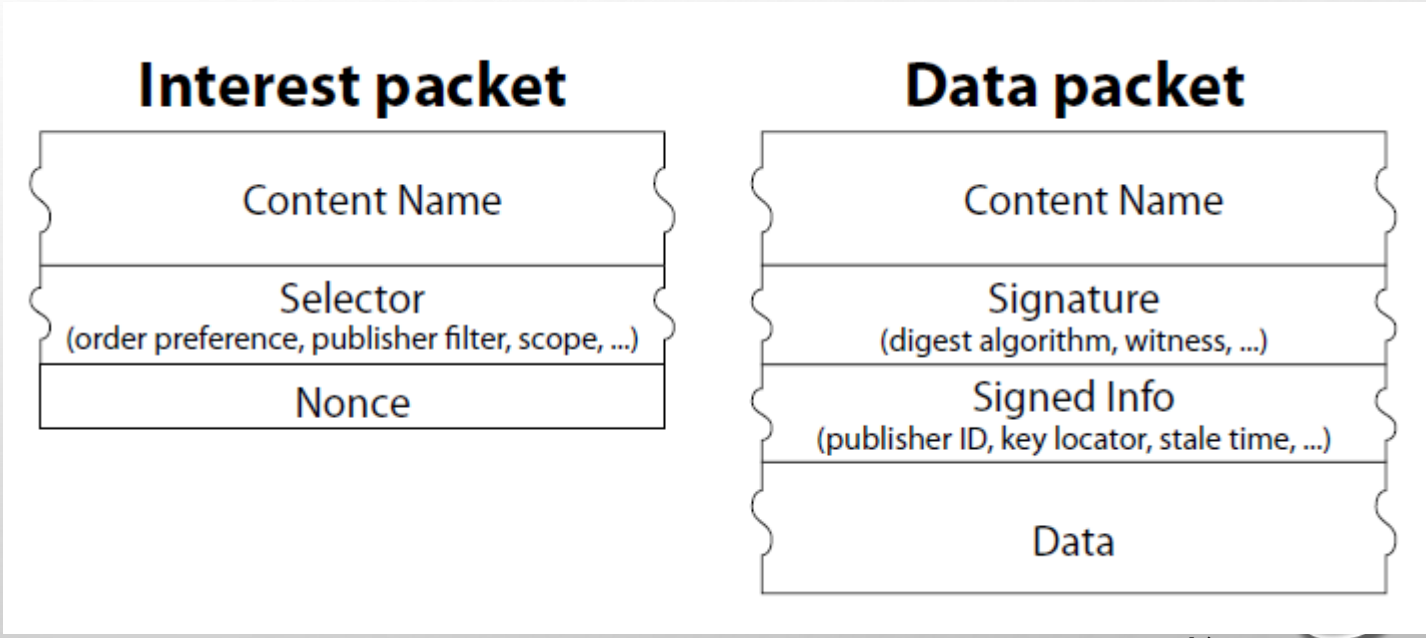
# 3. CCN/NDN OVERVIEWS (2) INTRODUCTION (2)

- Replace *where* with *what*.
- *Named data* is a better abstraction than *named hosts*.
  - A packet "address" names content, not location.
- Protocol stack for IP and CCN.
- IP simplicity is success of Internet.
- CCN has a simple network layer.
- CCN can be built on anything, including IP.



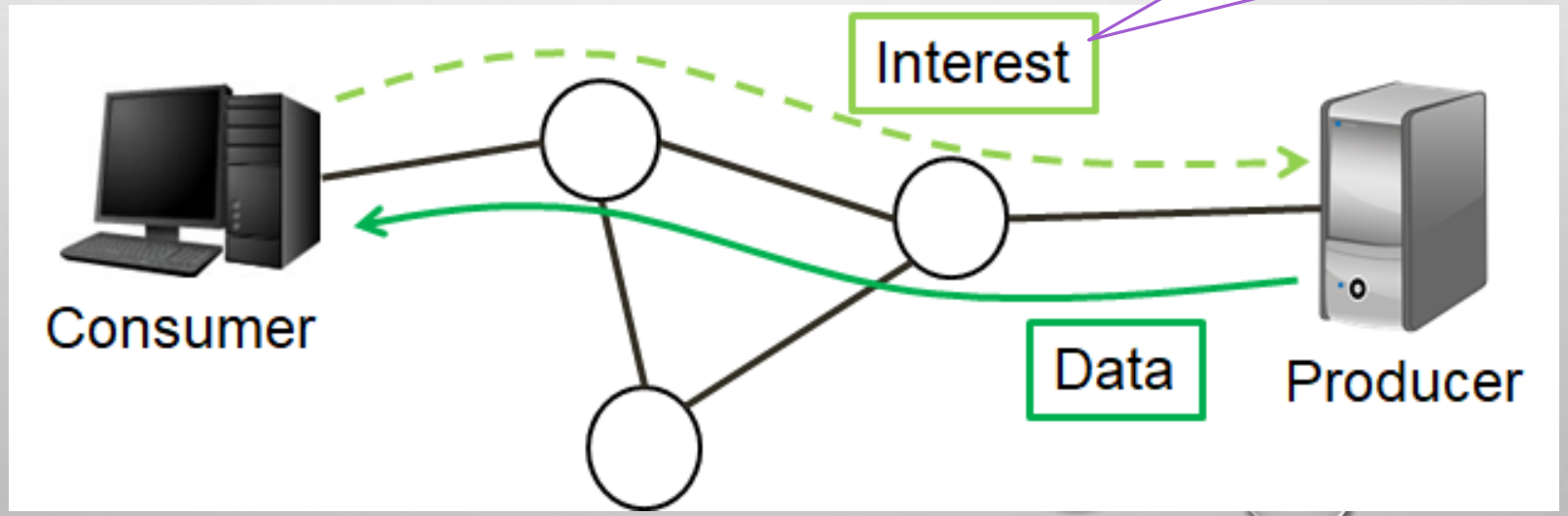
# 3. CCN/NDN OVERVIEWS (3)
# CCN NODE MODEL (1)

- CCN communication is driven by the customers of data.
- Two CCN packet types: Interest and Data.
  - Interest and Data has one-to-one relationship.
  - Data "satisfies" an Interest when ContentName in Interest is a prefix of ContentName in Data.
  - Nonce is used for checking duplication of Interest.
  - Signature is for Integrity of Data.



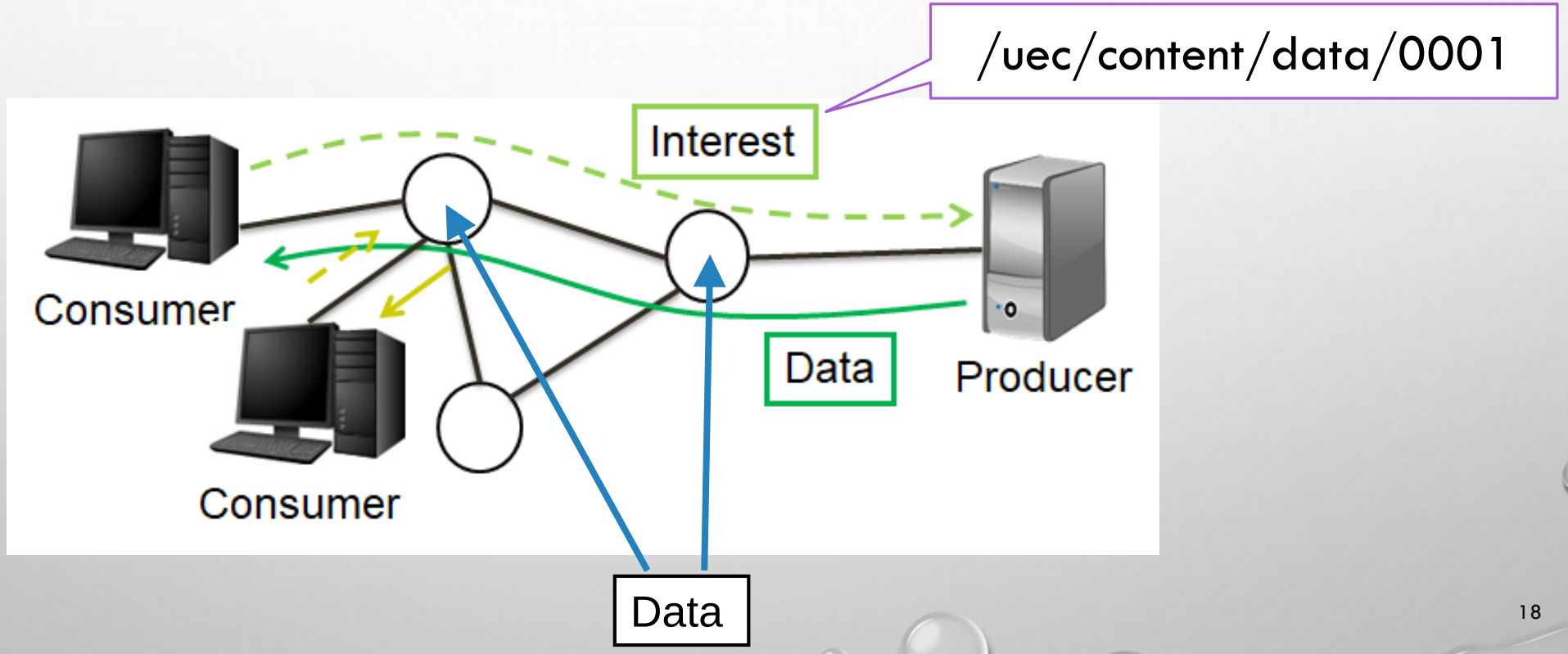
# 3. CCN/NDN OVERVIEWS (4)
# CCN NODE MODEL (2)

- Basic data transfer in CCN
  - Data is transferred in the reverse direction of Interest path.
  - No source and destination IP addresses in Interest and Data.
    - Producer does not know who requested.
    - Consumer does not know who sent the content.



# 3. CCN/NDN OVERVIEWS (5)
# CCN NODE MODEL (3)

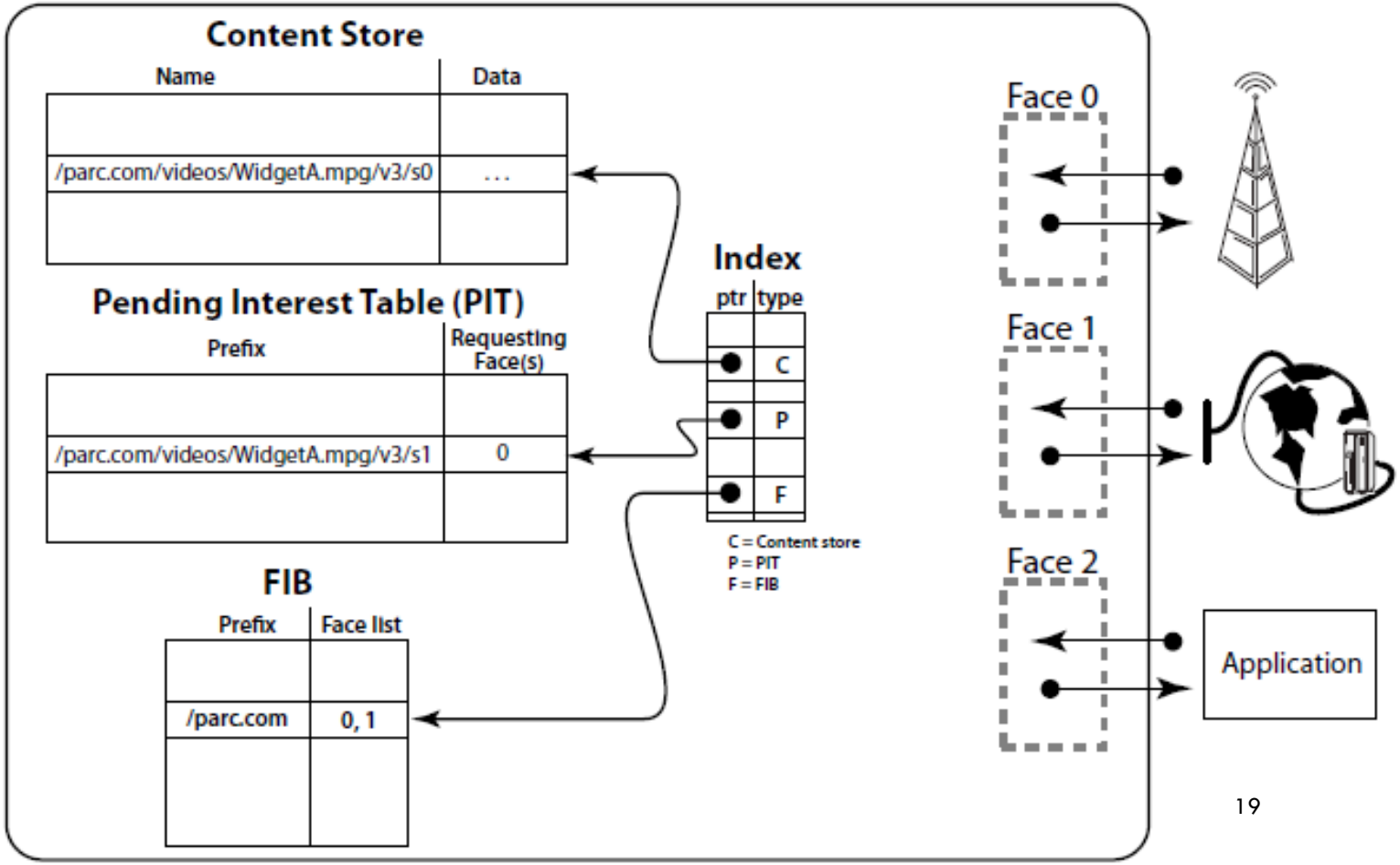
- CCN routers transferring the Data packet cache the packet for future redistribution.



# 3. CCN/NDN OVERVIEWS (6)
# CCN NODE MODEL (4)

CCN node [4]

- Three data structure:
  - CS, PIT, and FIB
- Multiple Interface called face
  - Interface to application is also face.



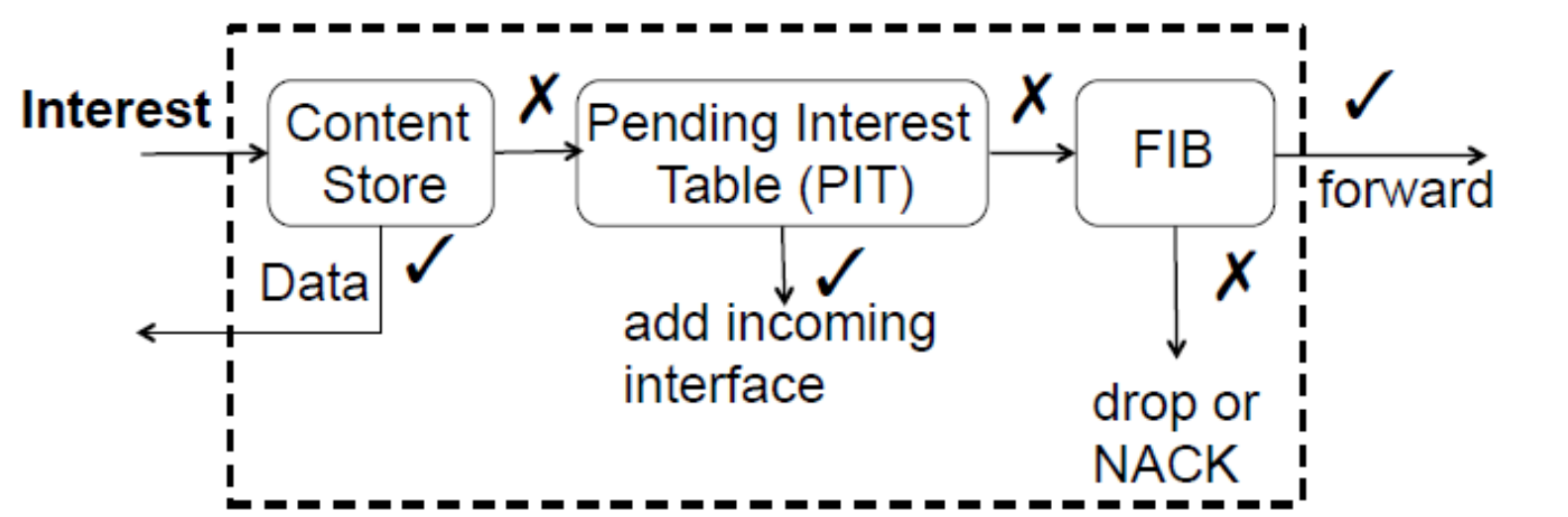
# 3. CCN/NDN OVERVIEWS (7)
# CCN NODE MODEL (5)

CCN node data structure

- Forwarding Interest Base (FIB): used to forward Interest packets toward producers of matching Data.
- Pending Interest Table (PIT): keeping track of Interest packets forwarded to producers so that returned Data packets can be sent to consumers.
- Content Store (CS): caching received Data packets temporarily.

# 3. CCN/NDN OVERVIEWS (8)
# CCN NODE MODEL (6)

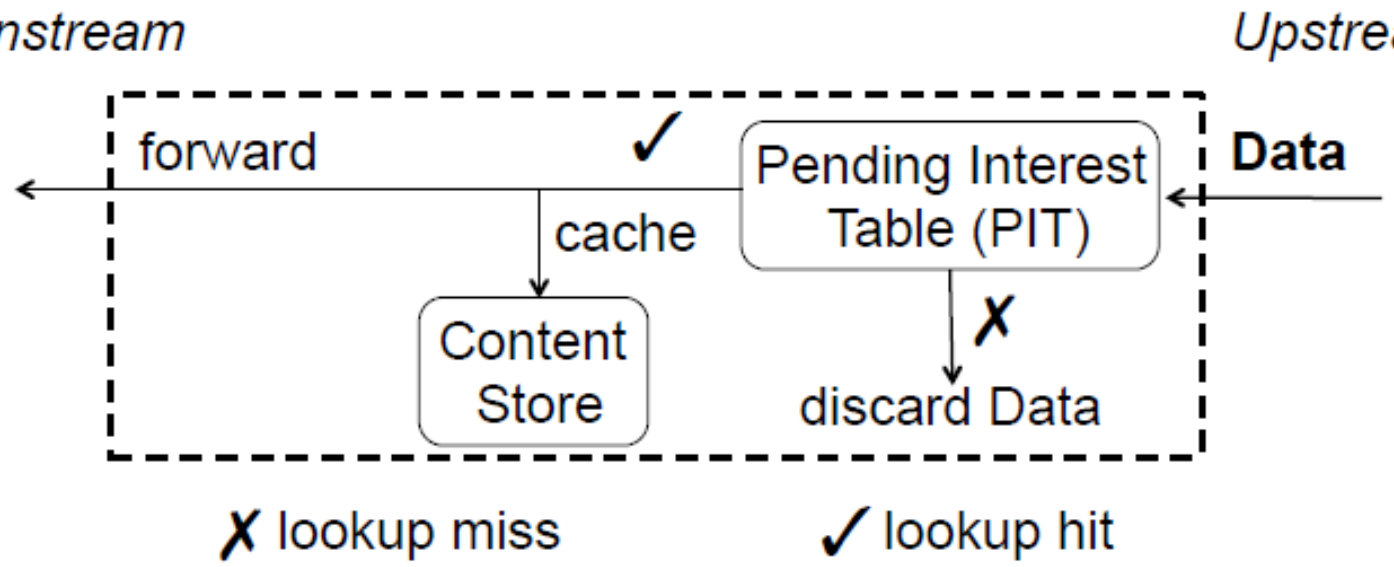
Interest packet arrival [5]




1. Check CS: send Data
2. Check PIT: add face
3. Check FIB: forward Interest
4. Discard

# 3. CCN/NDN OVERVIEWS (9)
# CCN NODE MODEL (7)

Data packet arrival [5]

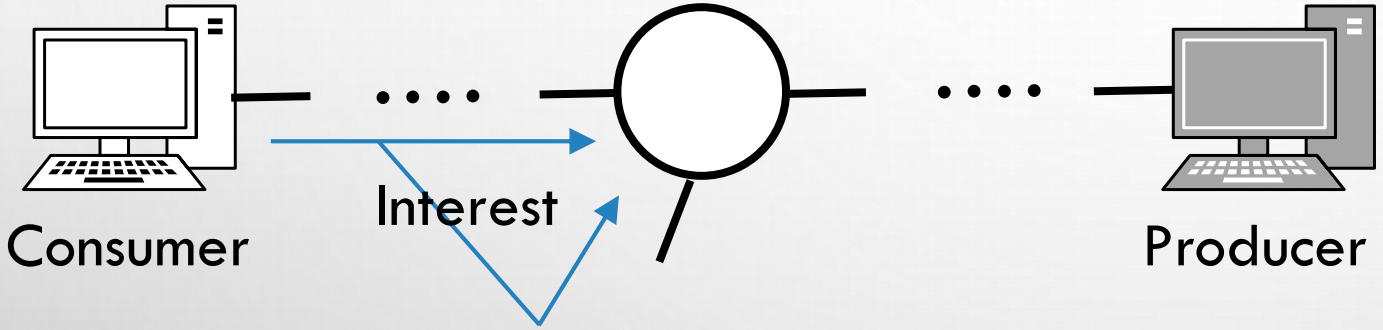


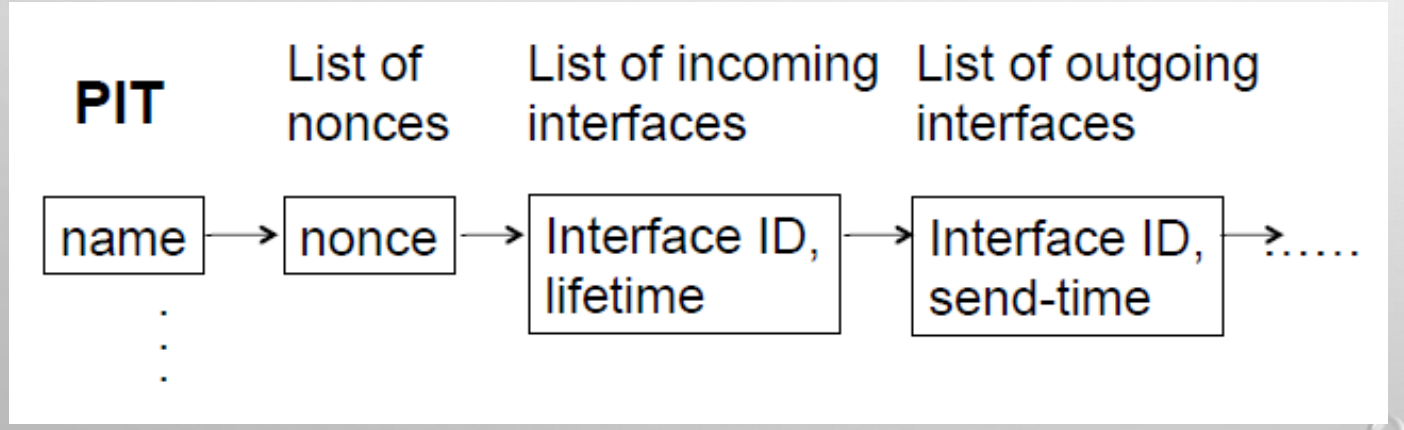

1. Check PIT: forward Data, Add CS
2. Discard

# 3. CCN/NDN OVERVIEWS (10)
# CCN NODE MODEL (8)

Details on Interest packet arrival (1)

- Duplicate check of Interest: nonce in Interest is used



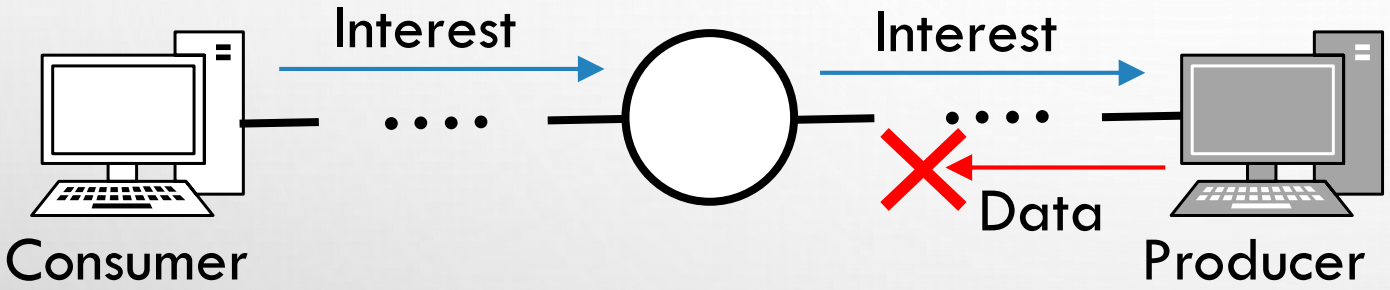



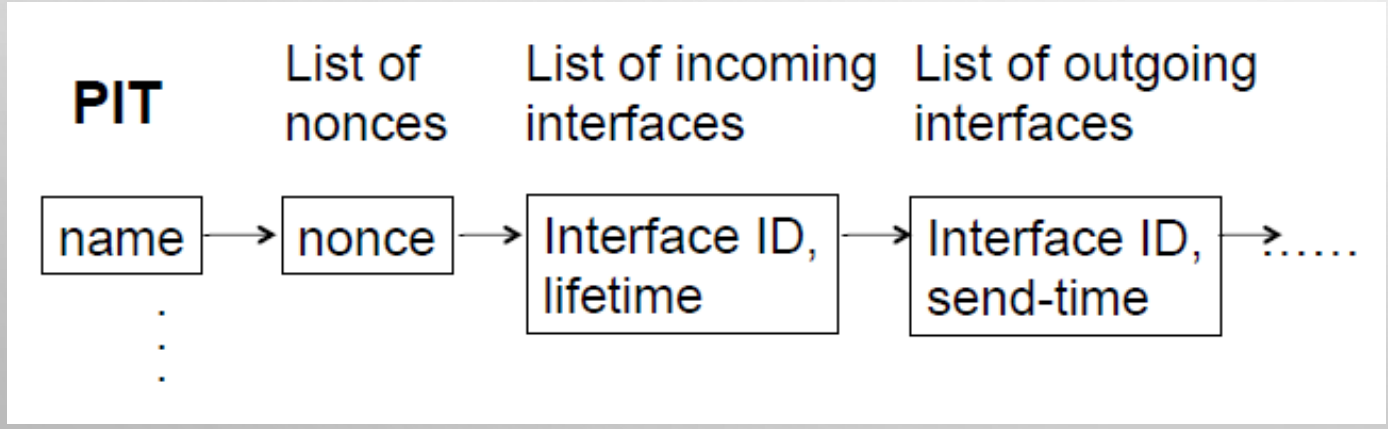

- Nonce is maintained in PIT [5].
- PIT is checked in the first place, before checking CS.

# 3. CCN/NDN OVERVIEWS (11)
# CCN NODE MODEL (9)

Details on Interest packet arrival (2)

- How long PIT entry is kept. PIT entries need to timeout.



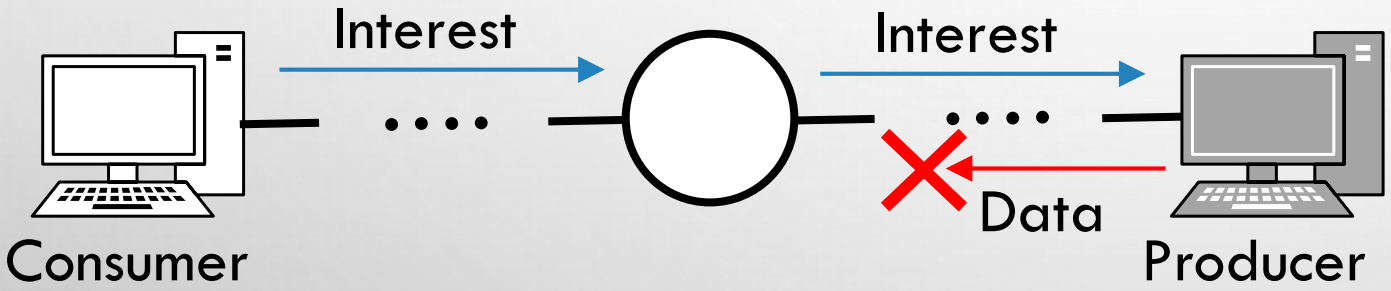




- Data packet may be lost.
- Lifetime is maintained in PIT [5].
- If lifetime is spent, the PIT entry will be discarded.

# 3. CCN/NDN OVERVIEWS (12)
# CCN NODE MODEL (10)

Details on Data packet handling

- If Data packet is lost, Consumer will retransmit it.




- Nonce in the retransmitted Interest may be the same one as the original Interest, or a new one.
- Retransmit timeout must be longer than lifetime of PIT entry.

# 3. CCN/NDN OVERVIEWS (13)
# NAME STRUCTURE (1)

- One content file is divided into multiple data segments.
- Each segment has its own name.
- Content name has hierarchical structure like URL.

content

Data 1

Data 2

Data 3

Data 4

/uec/content/data/0001

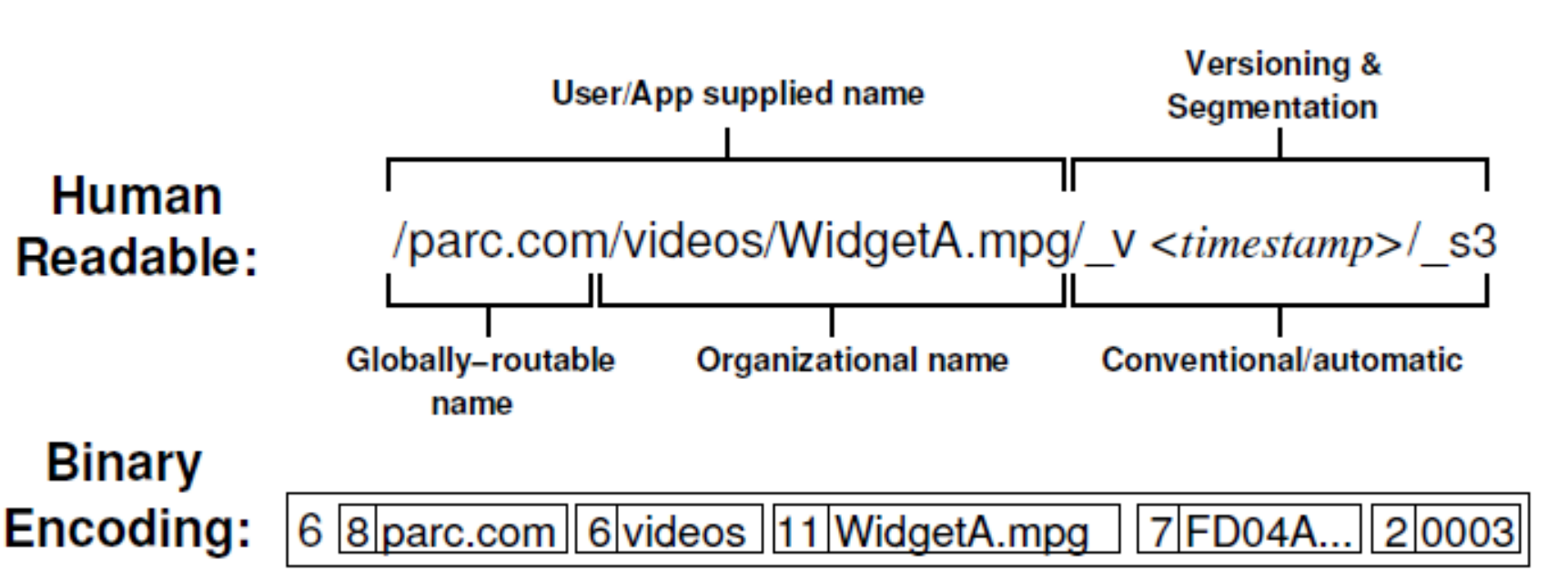
/uec/content/data/0002

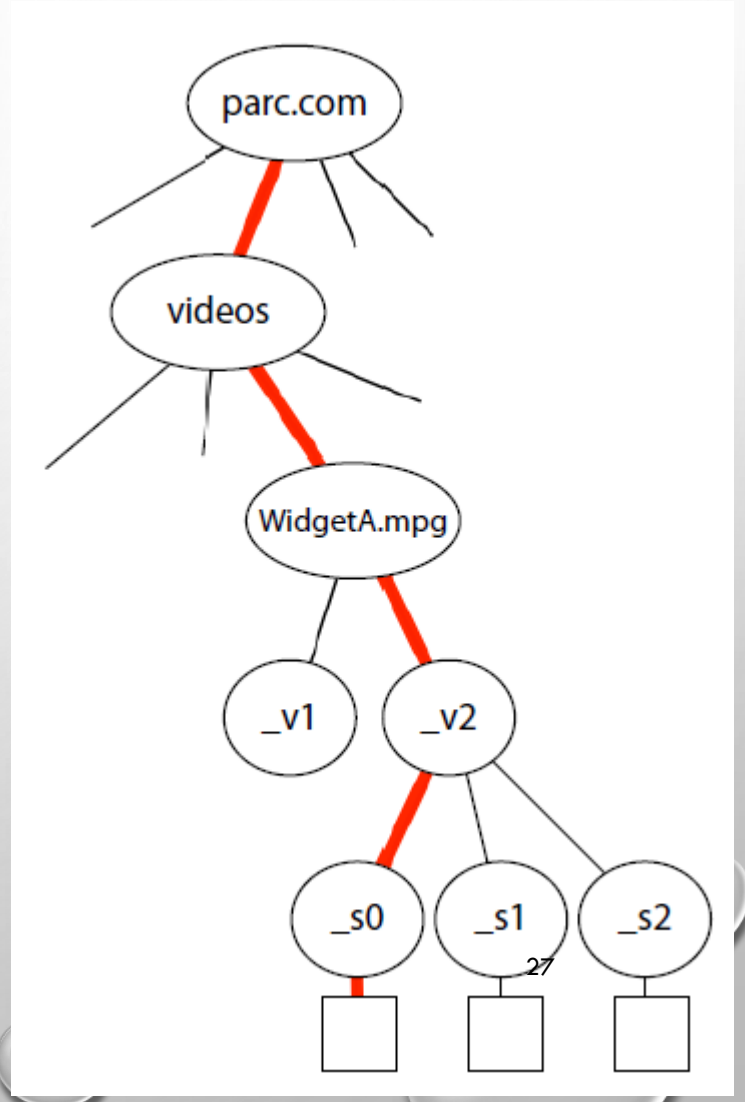
/uec/content/data/0003

/uec/content/data/0004

# 3. CCN/NDN OVERVIEWS (14)
# NAME STRUCTURE (2)

Content name example [4]



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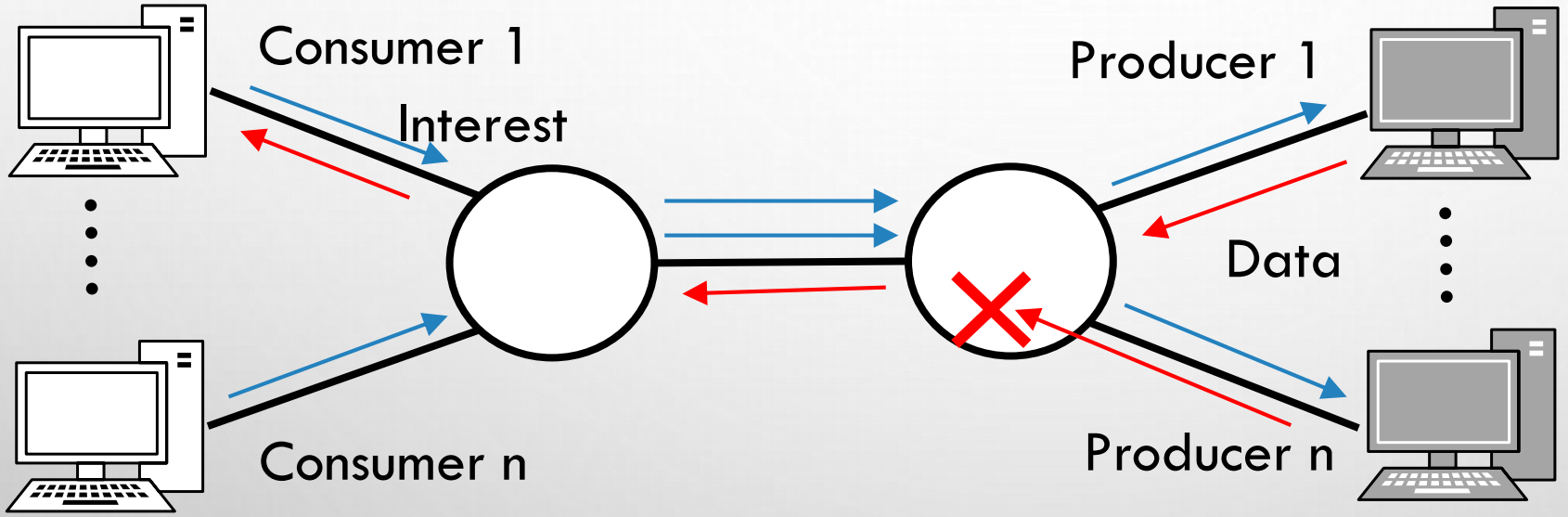
# 4. NDN CONGESTION CONTROL (1) OVERVIEW (1)

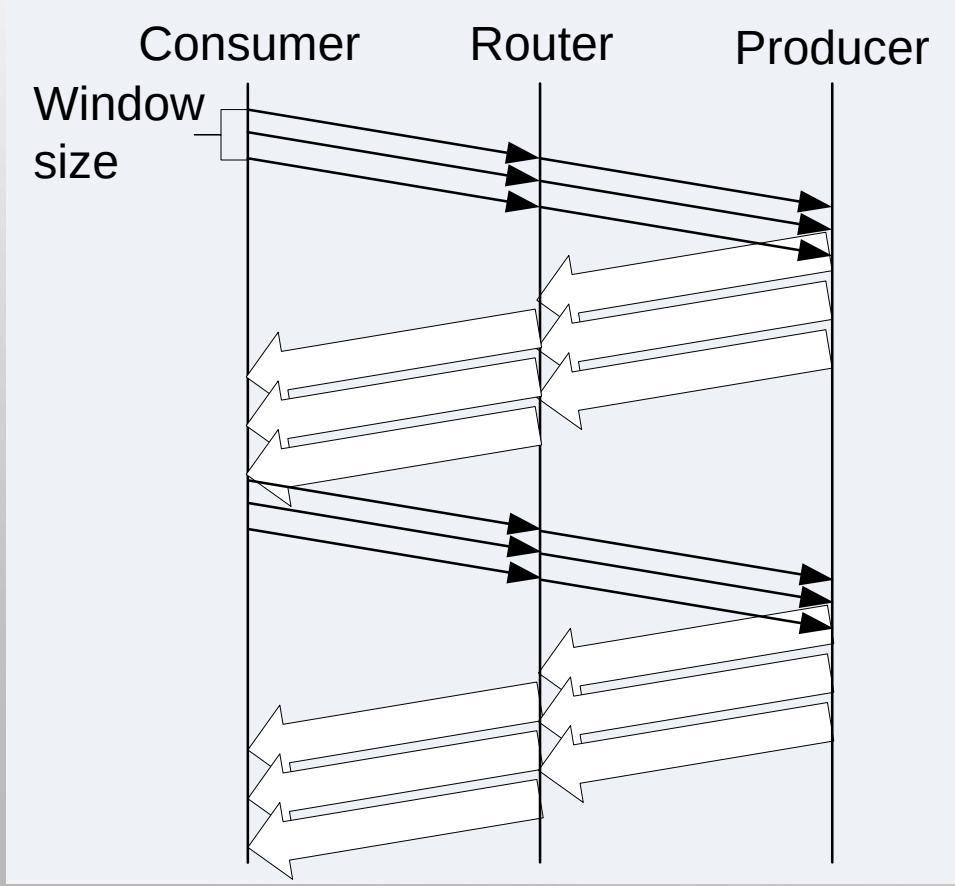
- Data packets may be stuck at a bottleneck link. Congestion

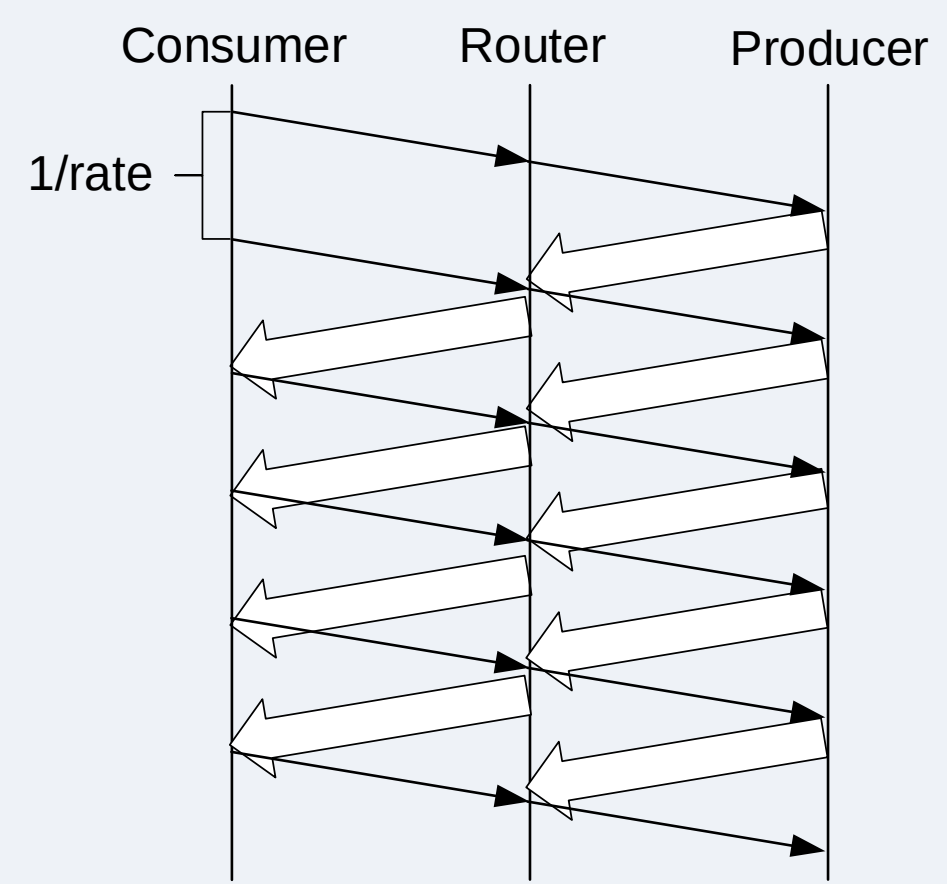


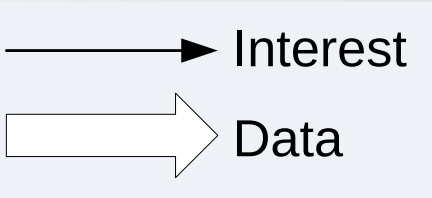

- Consumers need pace down the sending rate of Interest packets.
  - Similarity with TCP: Consumers (end nodes) need to respond eventually.
  - Difference with TCP: Router knows Interests. Cache exists……

# 4. NDN CONGESTION CONTROL (2) OVERVIEW (2)

- Many proposals. Categorized according to multiple criteria.
- How Interests are sent ? Window-based or rate-based.



# 4. NDN CONGESTION CONTROL (3) OVERVIEW (3)

- Who control Interest sending ? Consumer-driven or hop-by-hop.
  - Consumer-driven: Only consumer determines window size or rate.
  - Hop-by-hop: Intermediate routers join to determining window size/rate.
- How congestion is detected ? Timeout-based or congestion notification.
  - Timeout-based: When consumer detects timeout for Interest, it knows congestion.
  - Congestion notification: Intermediate routers inform consumer of congestion.
- How window size/rate is determined ? Non-deterministic or rate notification.
  - Non-deterministic: Consumer changes window size/rate according some predefined algorithm, such as AIMD (additive increase multiplicative decrease).
  - Rate notification: Intermediate routers informs consumer of optimum rate at congested link.

# 4. NDN CONGESTION CONTROL (4) RELATED WORK (1)

- Window-based approaches [6]

| how determined \ rate/window | who controls / how detected | window-based | |
|---|---|---|---|
| | | consumer initiative | hop-by-hop |
| non-deterministic. | timeout based | ICP [7], ICTP, CCTCP, HR-ICP | |
| | congestion notification | CHoPCoP [8], ECP | |
| rate notification | -- | | HWCC [6] |

ICP: Interest control protocol, ICTP: Information centric transport protocol, CCTCP: content centric TCP, HR-ICP: Joint hop-by-hop and receiver-driven Interest control protocol, CHoPCoP: Chunk-switched hop pull control protocol, ECP: Explicit control protocol, HWCC: Hop-by-hop window-based congestion control

# 4. NDN CONGESTION CONTROL (5) RELATED WORK (2)

- Rate-based approaches [6]

| how determined \ who controls | rate/window | rate-based | |
|---|---|---|---|
| how detected | | consumer initiative | hop-by-hop |
| non-deterministic. | timeout based | SIRC | |
| | congestion notification | | SF [5] |
| rate notification | -- | ECN-based | HoBHIS, MIRCC [9] |

SIRC: Self-regulating Interest rate control, SF: Stateful forwarding,

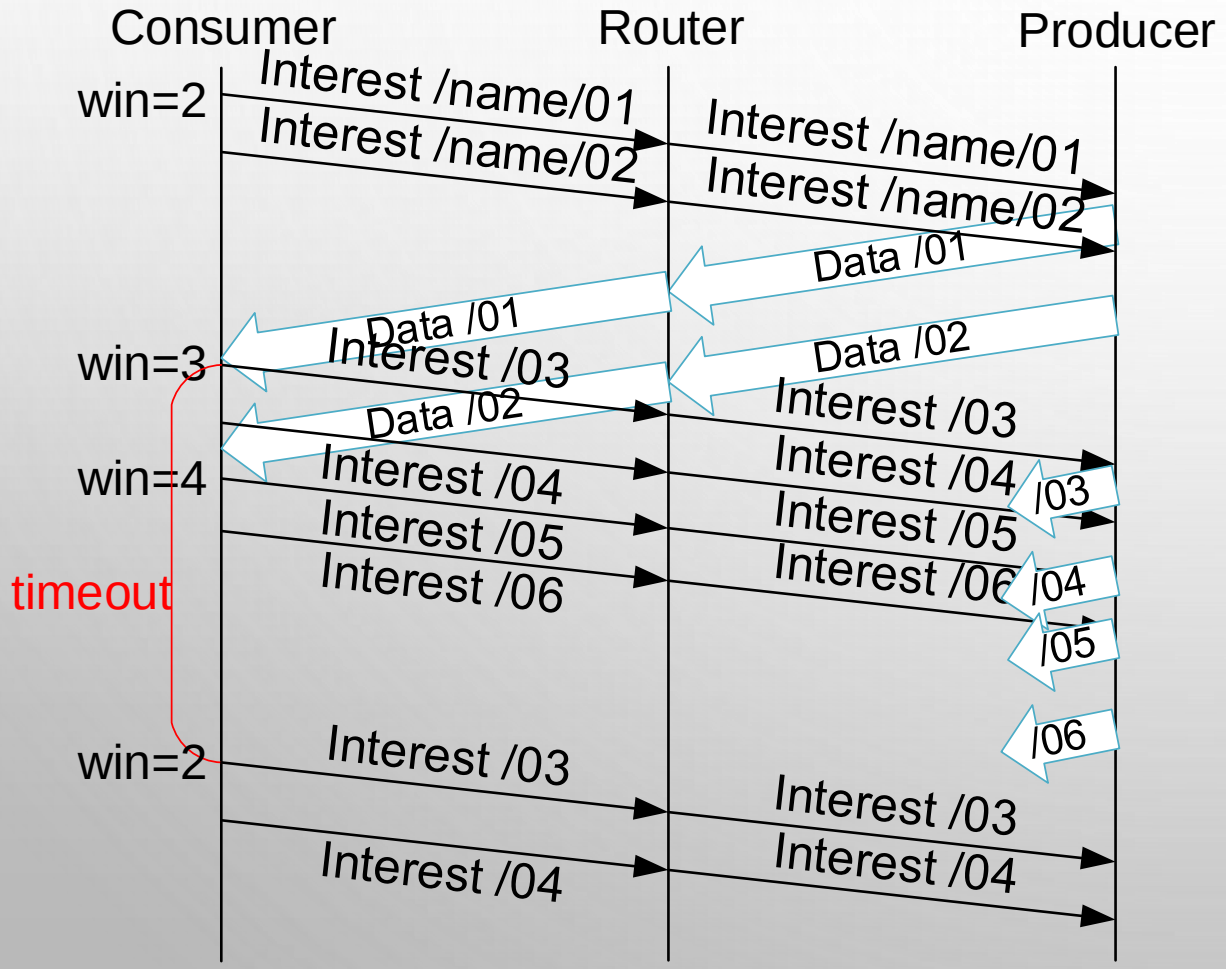
ECN-based: Explicit congestion notification based,

HoBHIS: Hop-by-hop Interest shaping,

MIRCC: Multipath-aware ICN rate-based congestion control

# 4. NDN CONGESTION CONTROL (6)
# ICP: INTEREST CONTROL PROTOCOL

- Basic window-based/timeout-based/AIMD approach




Consumer maintains window size. : win

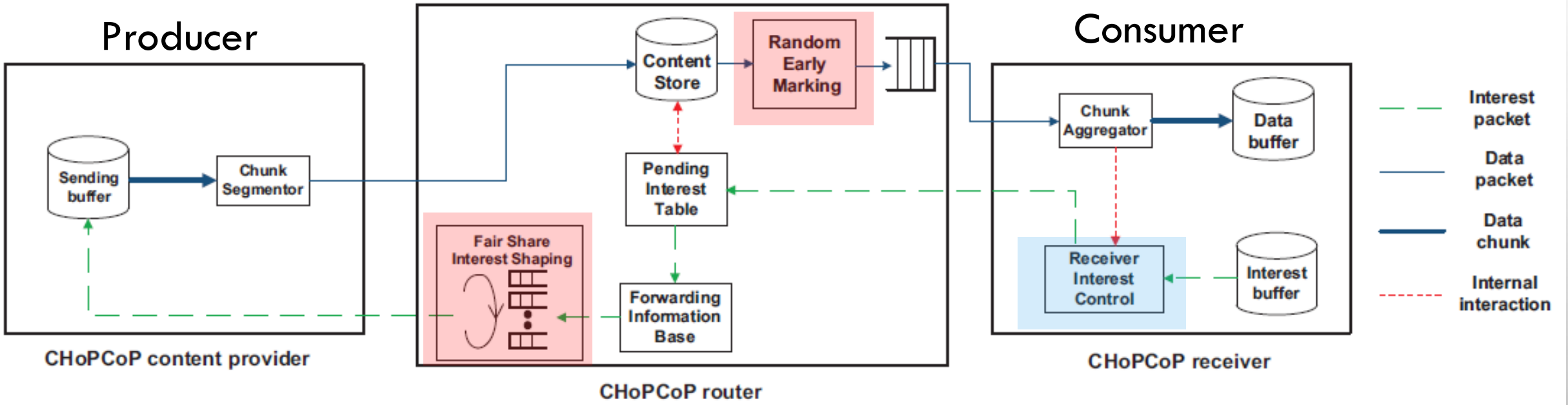
Each Data receipt: win = win+1

At timeout retransmission: win = win/2

Similar with TCP slow start

# 4. NDN CONGESTION CONTROL (7)
# CHoPCoP: Chunk-switched hop pull control protocol

- More sophisticated window-based approach [8]




Random Early Marking when congested. Interest shaping when more congested.

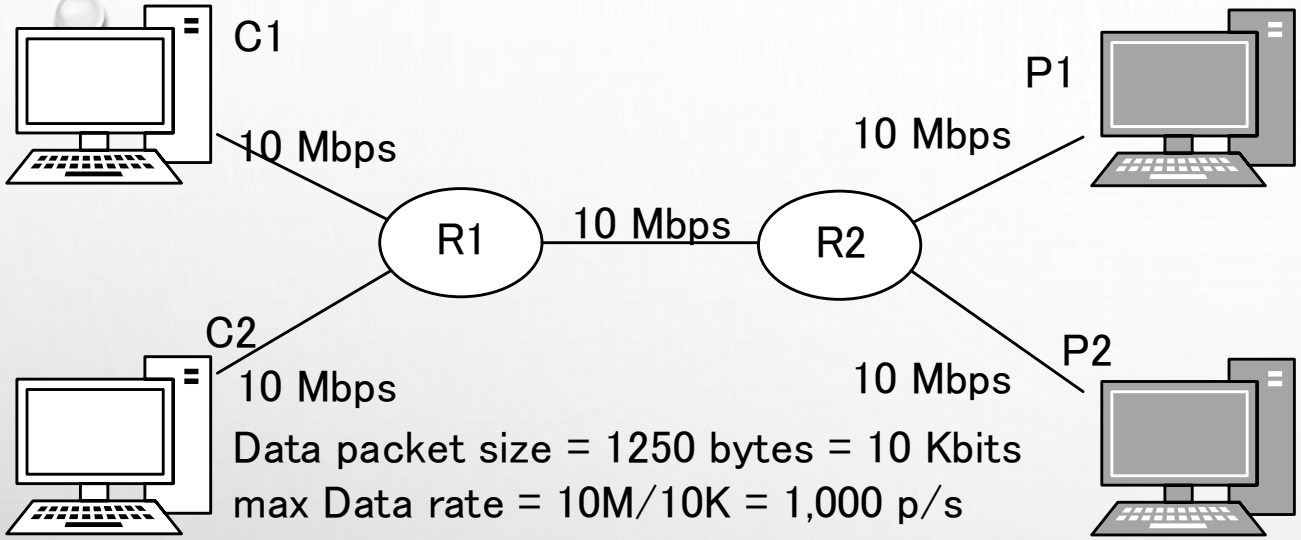
Slow start and congestion avoidance phases in window increasing.

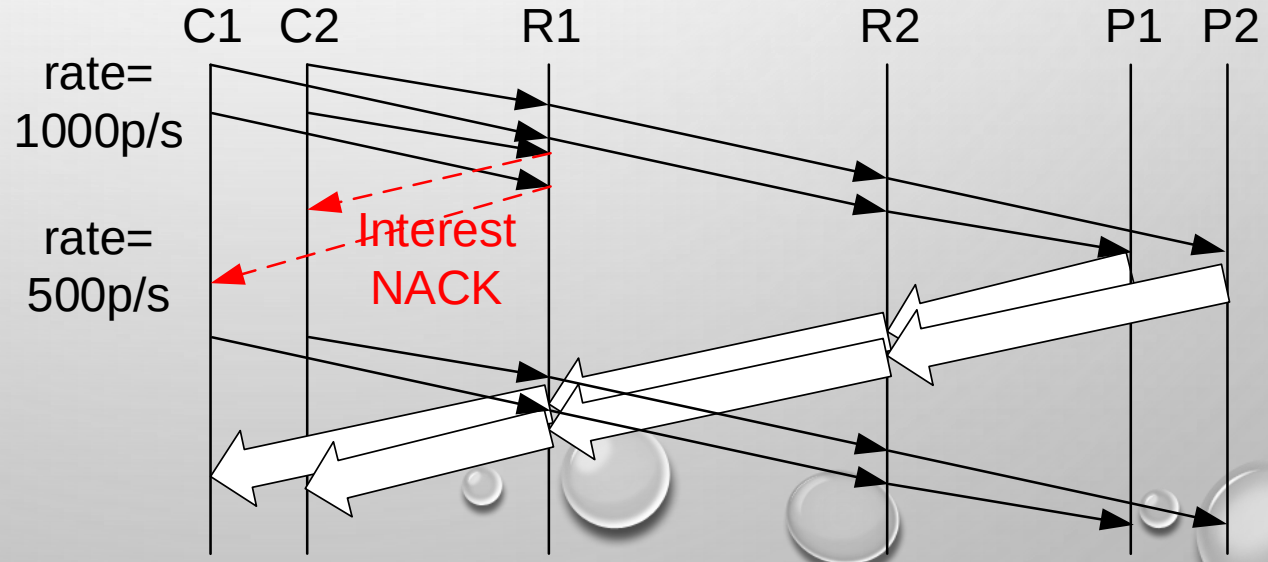
Different decreasing for timeout and marking.

# 4. NDN CONGESTION CONTROL (8)
# SF: STATEFUL FORWARDING (1)

- Rate-based approach by Jacobson group [5]
- Introduce Interest NACK packet reporting congestion.
  - Interest NACK is sent to consumer instead of Data packet.
  - When expected Data throughput exceeds link bandwidth, intermediate router discards Interest and sends Interest NACK.
- Rate control at consumer is non-deterministic, using AIMD.
  - Consumer increases rate at receiving Data packet.
  - Consumer halves rate at receiving Interest NACK, or timeout.

# 4. NDN CONGESTION CONTROL (9)
# SF: STATEFUL FORWARDING (2)

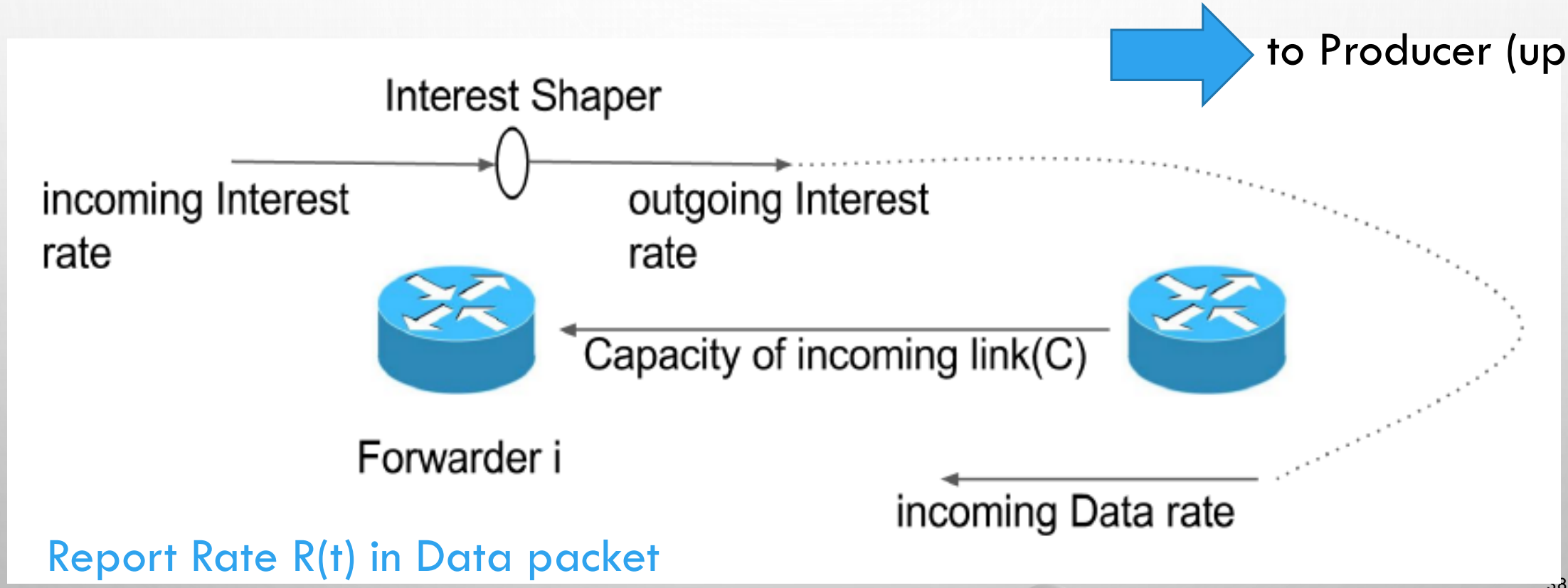


# 4. NDN CONGESTION CONTROL (10)

## MIRCC: Multipath-aware ICN rate-based congestion control (1)

- Intermediate routers report rate of upstream link in Data packet [9]

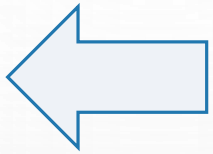


# 4. NDN CONGESTION CONTROL (11)

## MIRCC: Multipath-aware ICN rate-based congestion control (2)

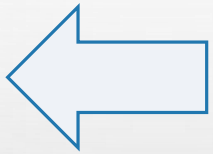
- Rate estimation in intermediate routers [9]

$$\hat{N} = max(C, y(t))/R(t-T)$$



estimated number of flows

$$base\_rate(t) = \frac{\eta C - \beta(t)\frac{q(t)}{d(t)}}{\hat{N}}$$



estimated rate for one flow

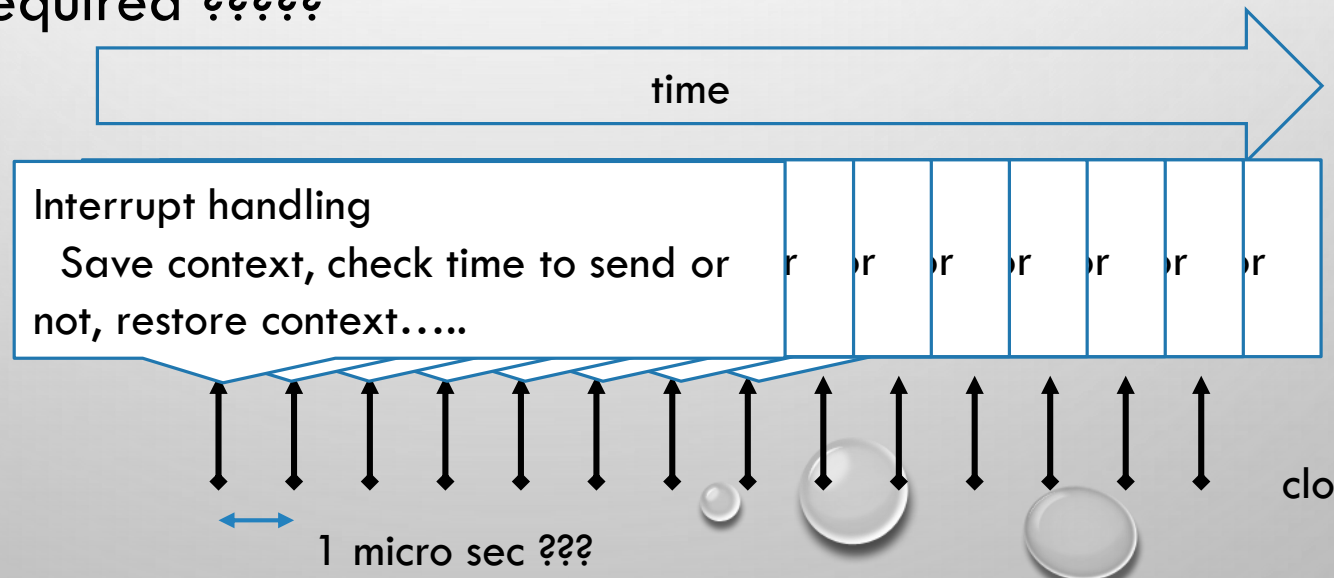
$T$: calculation interval, $C$: capacity of upstream link, $\eta$: target link utilization, $q(t)$: queue size, $d(t)$: RTT, $\beta(t)$: self-tuned parameter

# 4. NDN CONGESTION CONTROL (12)

## MIRCC: Multipath-aware ICN rate-based congestion control (3)

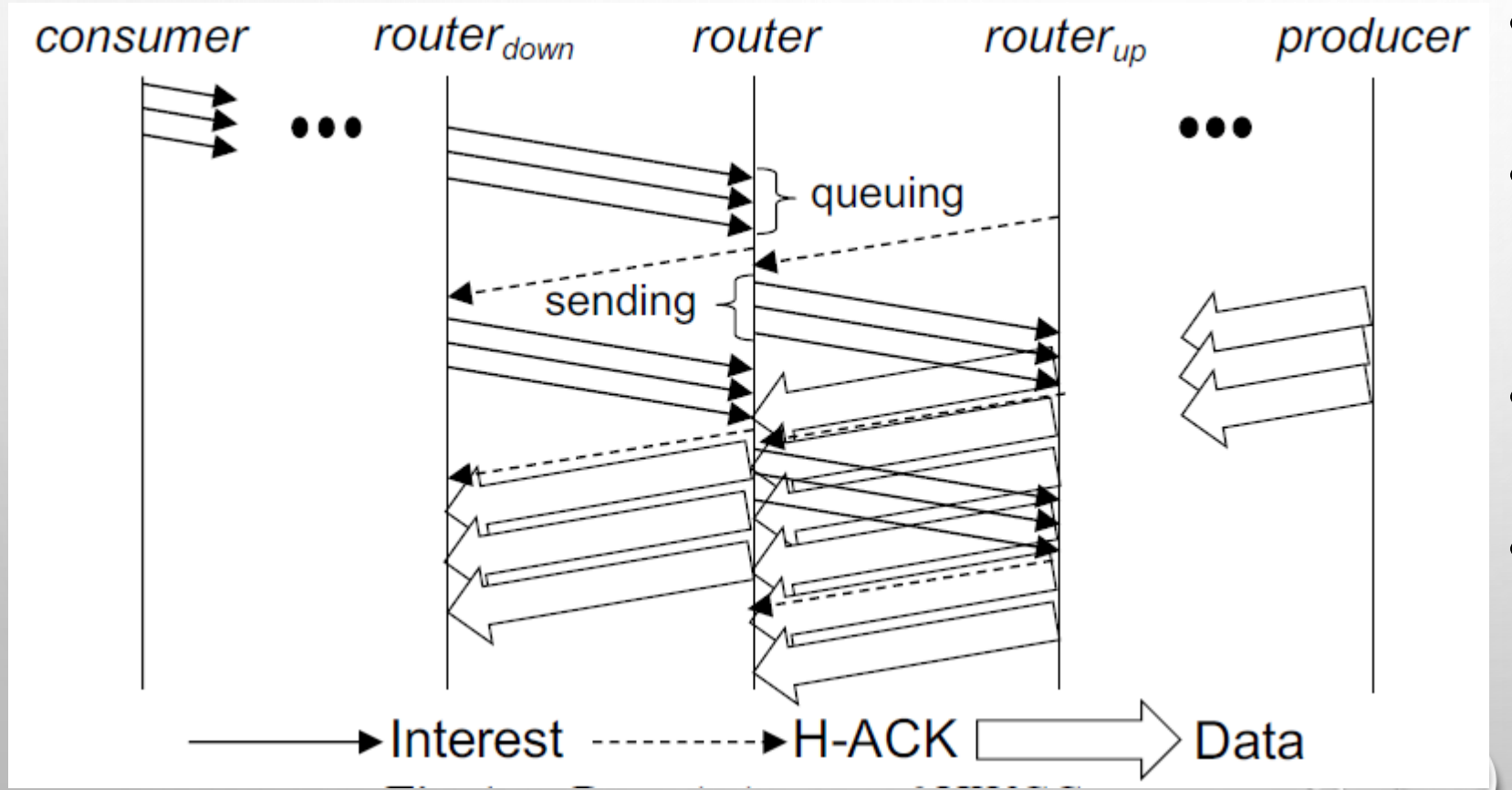
- MIRCC is very effective, but one of problems in rate-based approach is clock accuracy [10].
- Overhead of fine-grained rate control
  - 10Kbit/packet, 100Mbps => every 100 msec
  - 10Kbit/packet, 80Mbps => every 125 msec
  - 10Kbit/packet, 60Mbps => every 167 msec
  - What clock value is required ?????

- Overhead of hardware interrupt handling



# 4. NDN CONGESTION CONTROL (13)
# HWCC: Hop-by-hop window-based congestion control

- Use per link flow control [6]. Resolve weakness of window base. No accurate clock.




- Introduce Per hop ACK (H-ACK).
- Window size is determined per link basis,
  according to rate.
- Rate is reported in H-ACK and Interest.
- It is determined by router,
  - according to upstream and downstream status.

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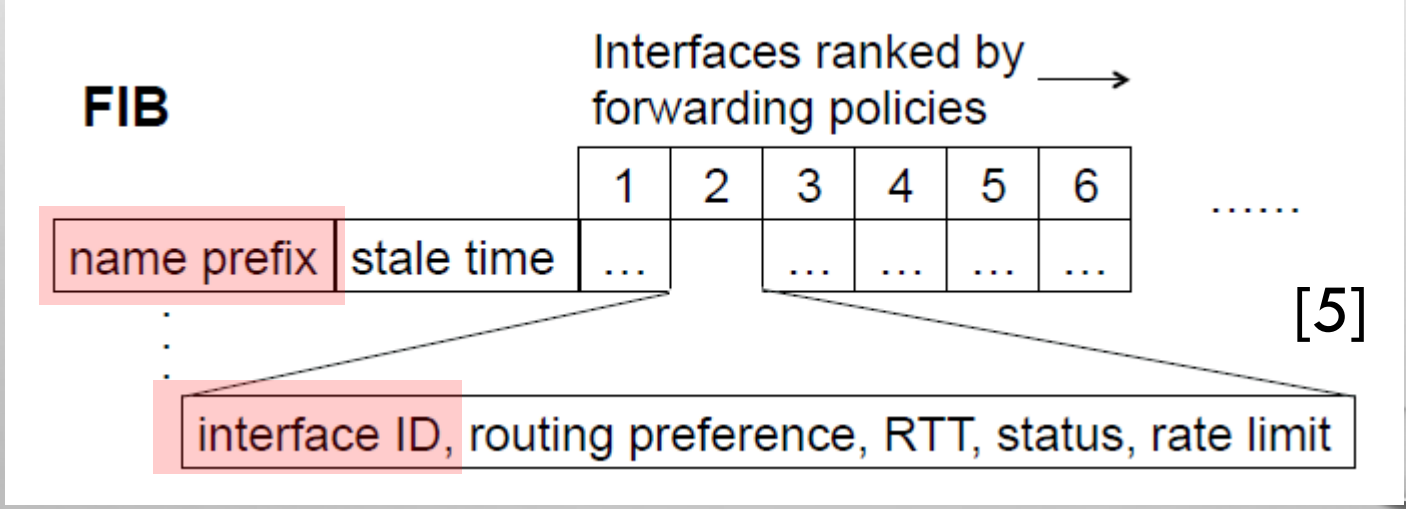
# 5. NDN ROUTING (1)
# OVERVIEW (1)

- FIB (Forwarding Information Base) is a sort of routing table in NDN nodes.
  - New Interest packets look for FIB entry to select outgoing face.
  - If there are no FIB entries, Interest packets are discarded.
- In small network, FIB can be specified by hand. Corresponding to Static routing.
- In large network, mechanisms are required to advertise name prefixes.

NDN routing




[5]

# 5. NDN ROUTING (2)
# OVERVIEW (2)

- Different approaches for wired network and wireless network.
- Wired network: Based on link state routing protocol in Internet (OSPF: Open Shortest Path First).
  - Exchange neighbor information (IP subnet address, link bandwidth, . . .) with neighbors.
  - Share network topology information among all nodes.
  - Construct routing table using shortest path in individual nodes.
- OSPFN: OSPF for Named-data
- NLSR: Named-data Link State Routing protocol [11]

# 5. NDN ROUTING (3)
# OVERVIEW (3)

- Wireless network: Proactive and reactive approaches.
- Proactive approach:
  - Similar with routing in wired network.
  - Exchange routing information periodically, and prepare routing table in advance of communication.
- MobileCCN: NDN nodes regularly exchange their own FIB (similar to RIP).
- TOP-CCN [12]: Extension of Optimized Link State Routing (OLSR).

- Reactive approach: Arrange routing information at communication.
- E-CHANET, REMIF [13]: Broadcast Interest packets. No FIB.
- Minh et al. [14]: Broadcast the first Interest. Returning Data makes FIB entry.

# 5. NDN ROUTING (4)
# NLSR (1)

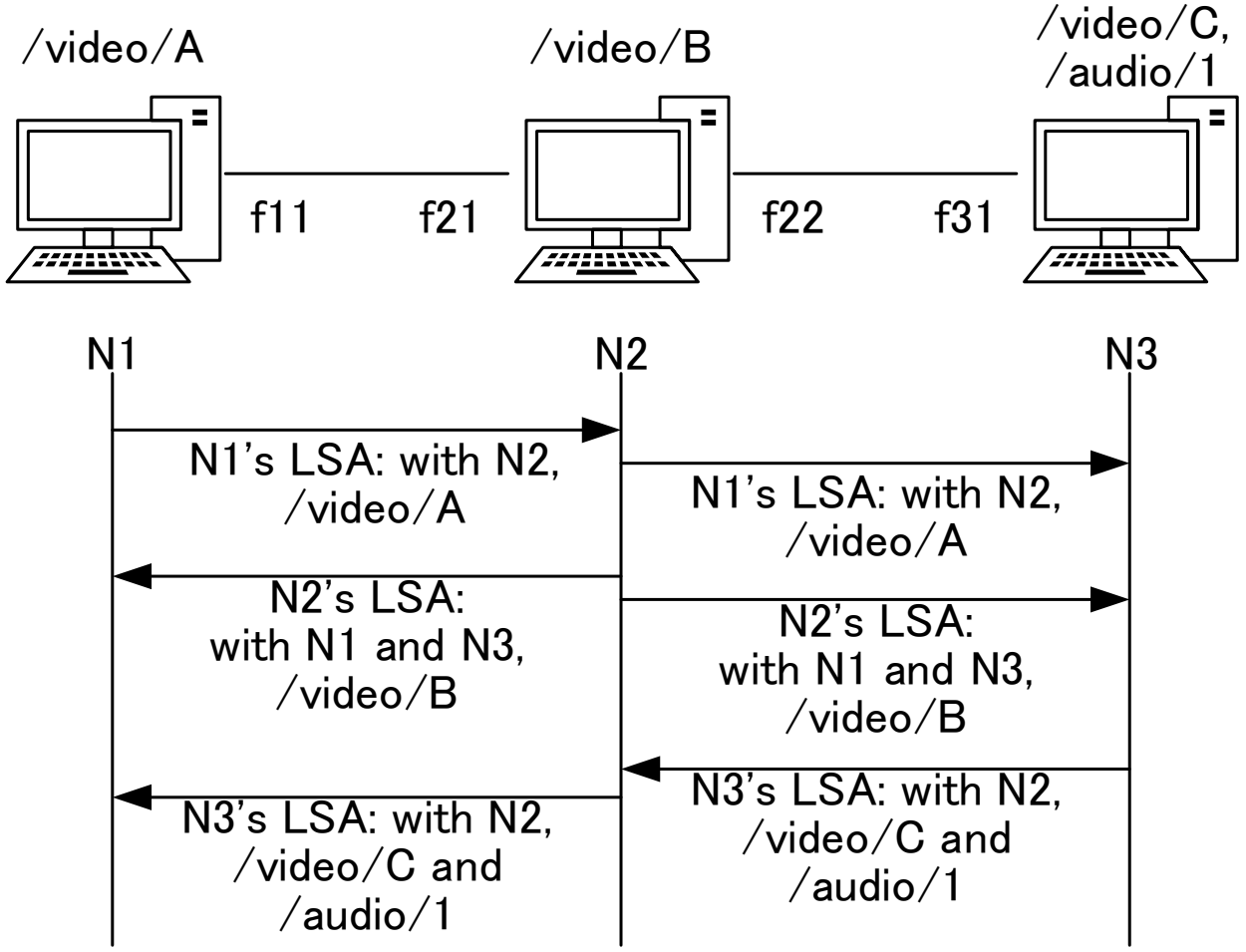
- Exchange LSA (Link State Advertisement) with neighbor node [10]
- LSA contains Neighbor name, Link cost to neighbor, Name prefix

**Table 1: Contents of an LSA**

| Type | Content |
|---|---|
| Adjacency LSA | # Active Links (N), Neighbor 1 Name, Link 1 Cost, ..., Neighbor N Name, Link N Cost |
| Prefix LSA | isValid, Name Prefix |

# 5. NDN ROUTING (5)
# NLSR (2)

- Overview of communication sequence and FIB construction



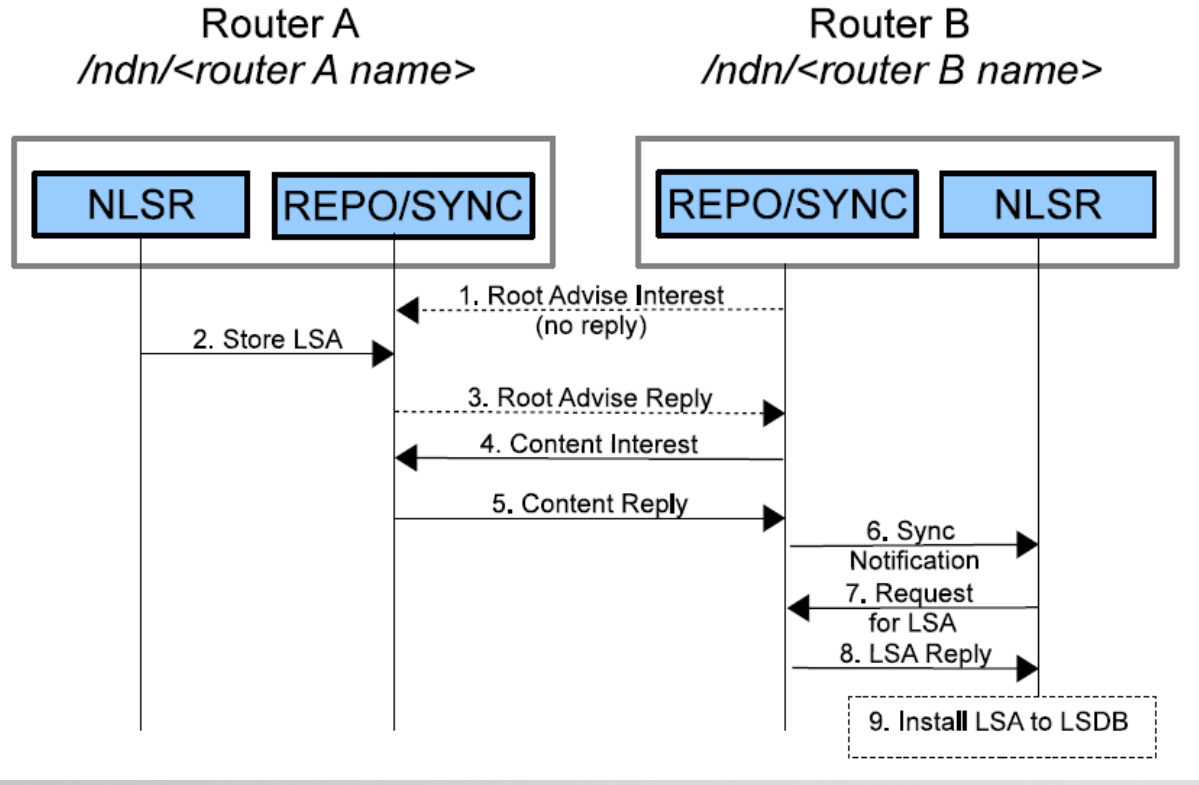

FIB

| | | |
|---|---|---|
| N1 | /video/A | itself |
| | /video/B | f11 |
| | /video/C | f11 |
| | /audio/1 | f11 |

| | | |
|---|---|---|
| N2 | /video/A | f21 |
| | /video/B | itself |
| | /video/C | f22 |
| | /audio/1 | f22 |

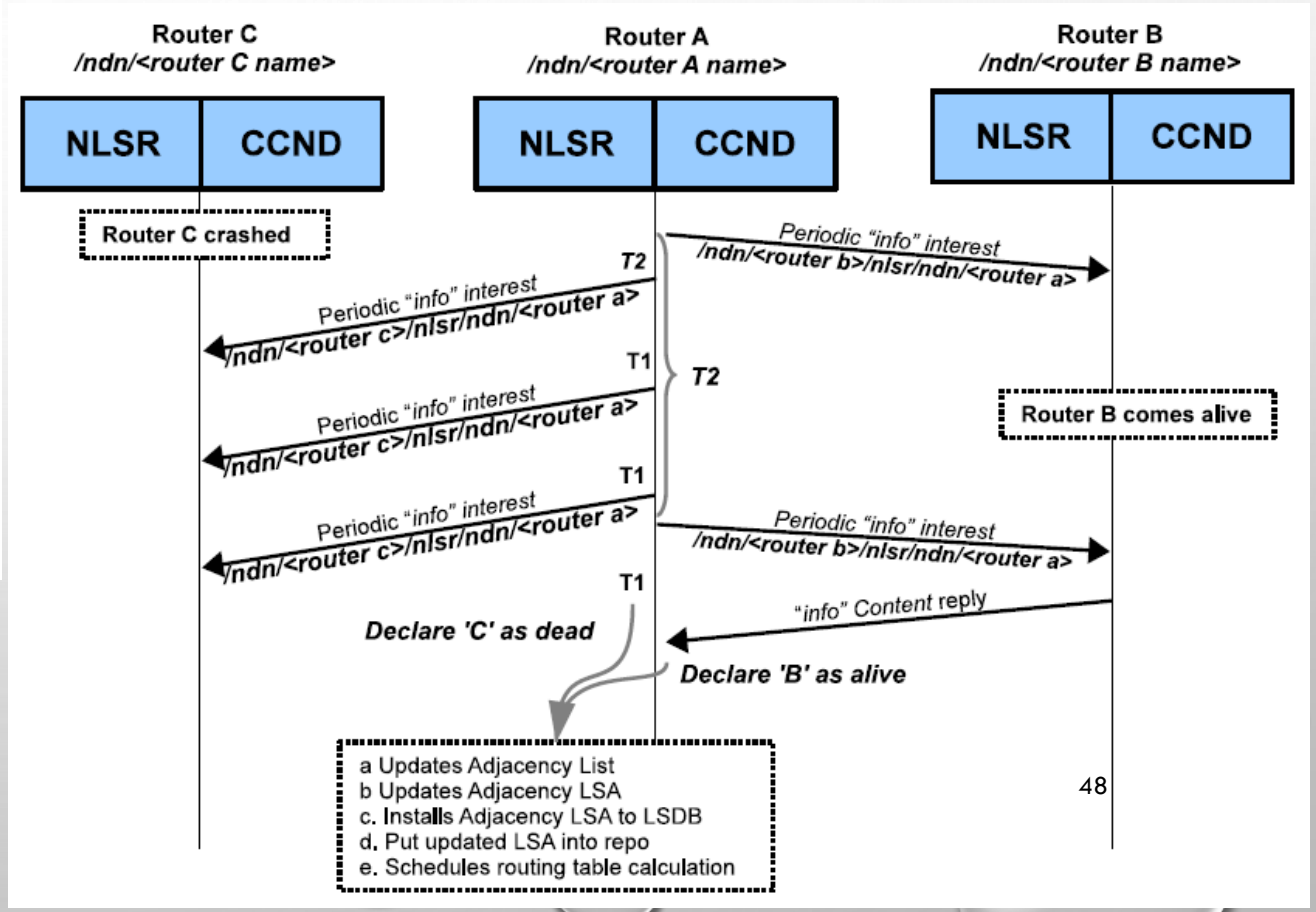
| | | |
|---|---|---|
| N3 | /video/A | f31 |
| | /video/B | f31 |
| | /video/C | itself |
| | /audio/1 | itself |

# 5. NDN ROUTING (6)
# NLSR (3)



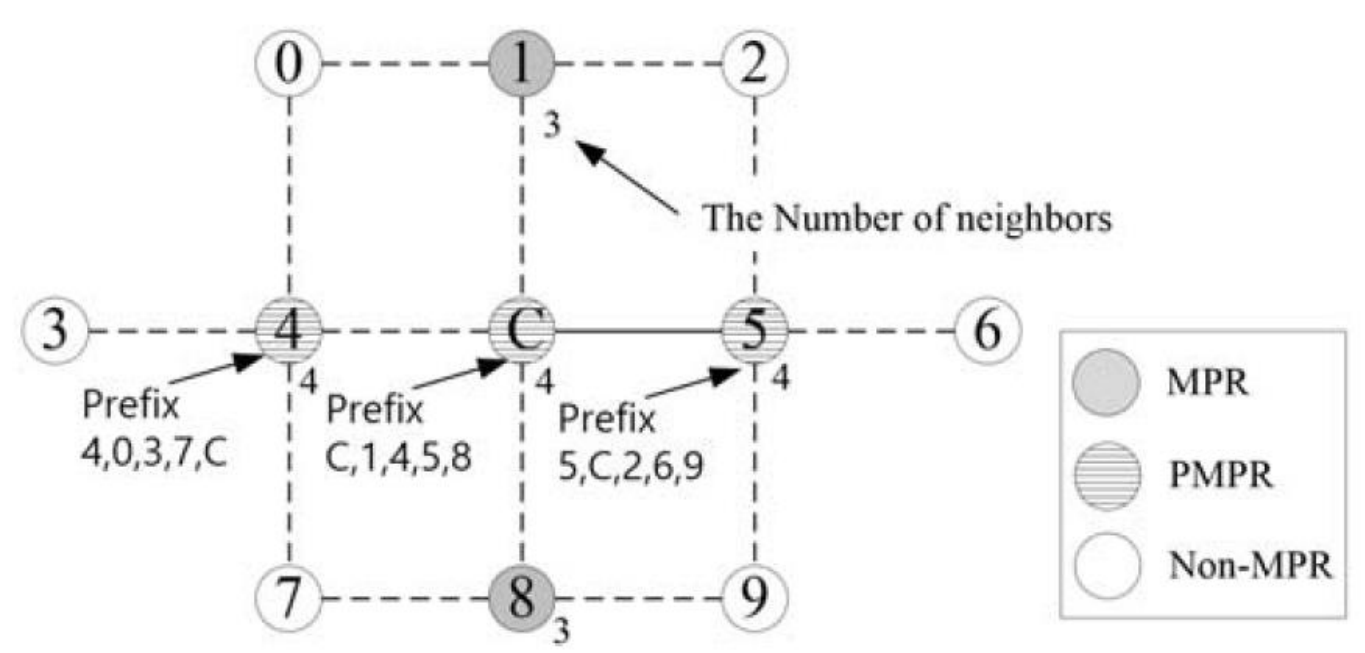

LSA advertisement

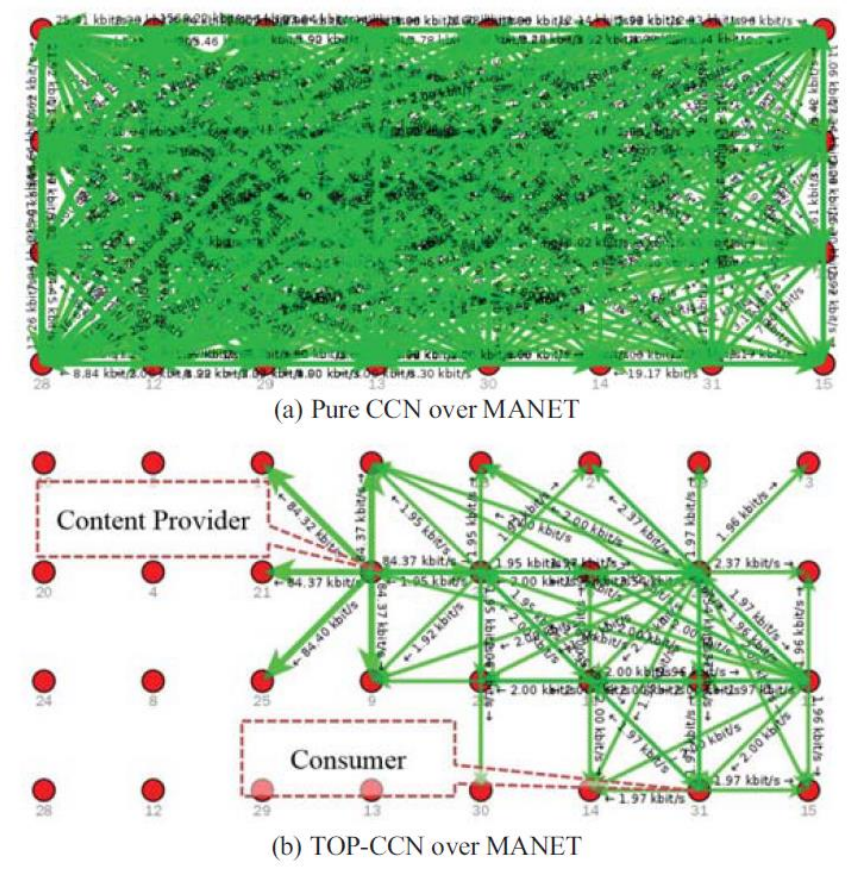
Failure detection



# 5. NDN ROUTING (7)
# TOP-CCN

- Proactive routing for NDN ad hoc network [12].
- Application of OLSR to NDN.  Use concept of MPR (Multiple Point Relay).

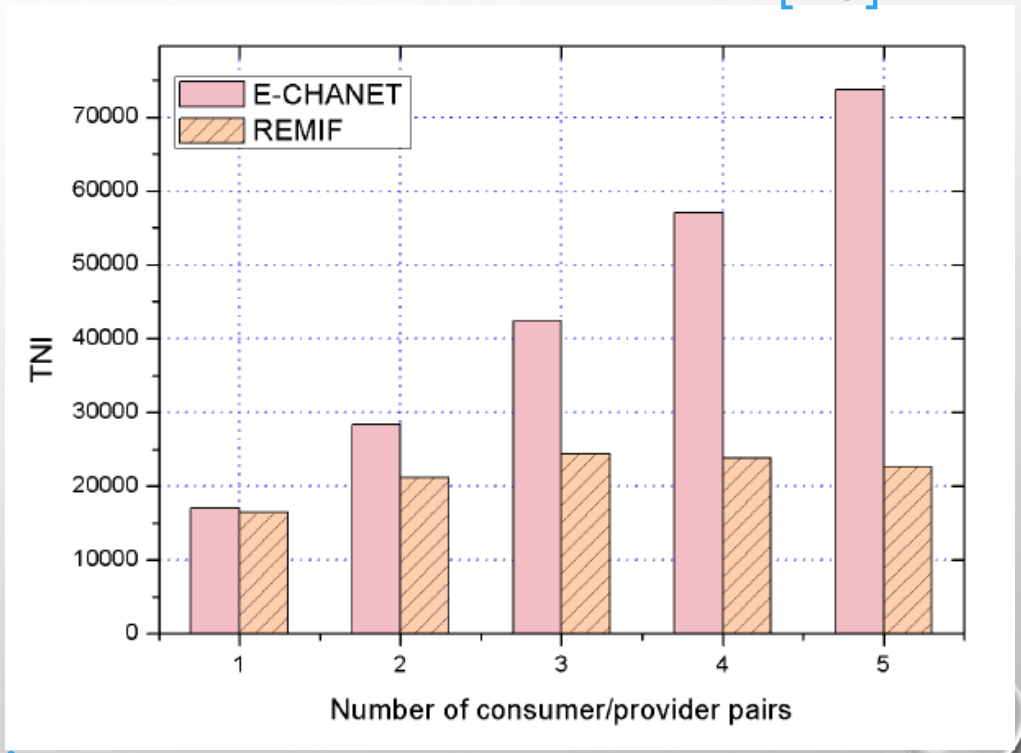


# 5. NDN ROUTING (8)
## REMIF (Robust and Efficient Multipath Interest Forwarding)

- Reactive routing for NDN ad hoc network [13].
- No FIB. Interest packets are always flooded.
- In order to suppress Interest forwarding storm, it introduces random delay in forwarding Interest.
  - If the same Interest arrives during the delay, discard the old one.

Total number of Interests [13]

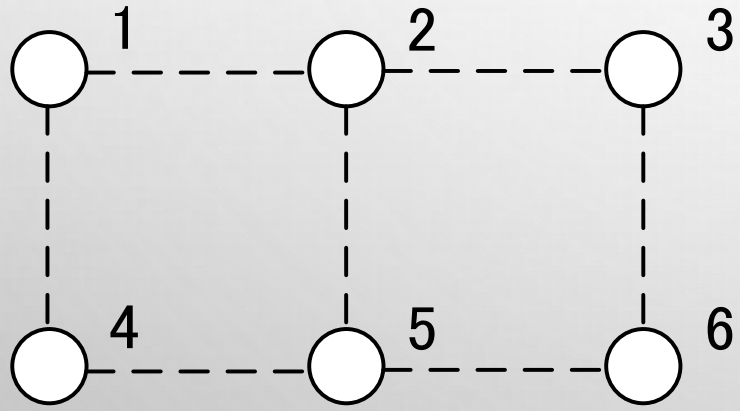



50 nodes in 700X700 m area.

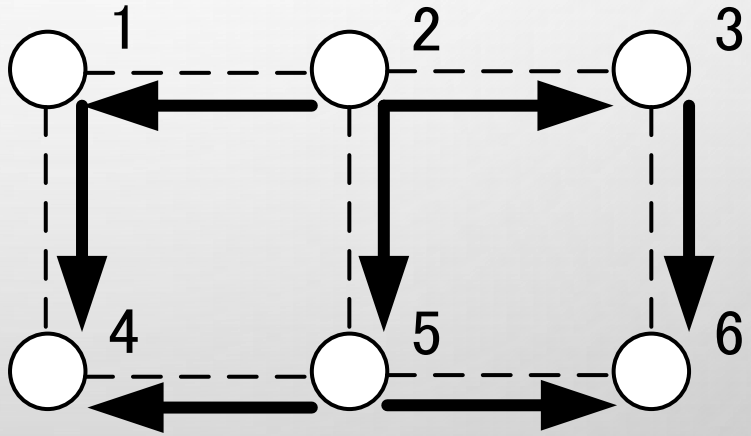
Each content has 400 message.

# 5. NDN ROUTING (9)
# HYBRID ROUTING APPROACH (1)

- Ad hoc network in shopping mall, station….
- Provider side nodes:  Fixed position.
- Consumer side nodes:  Mobile nodes.
- Proactive routing for provider side, and reactive routing for consumer side.




(a) example network

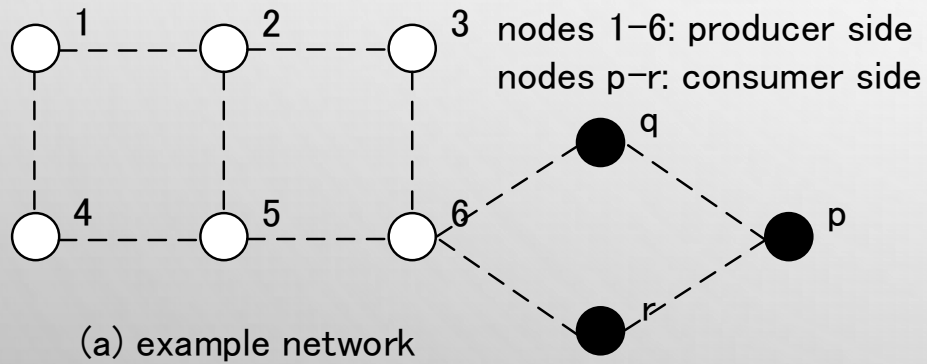



(c) generated DAG

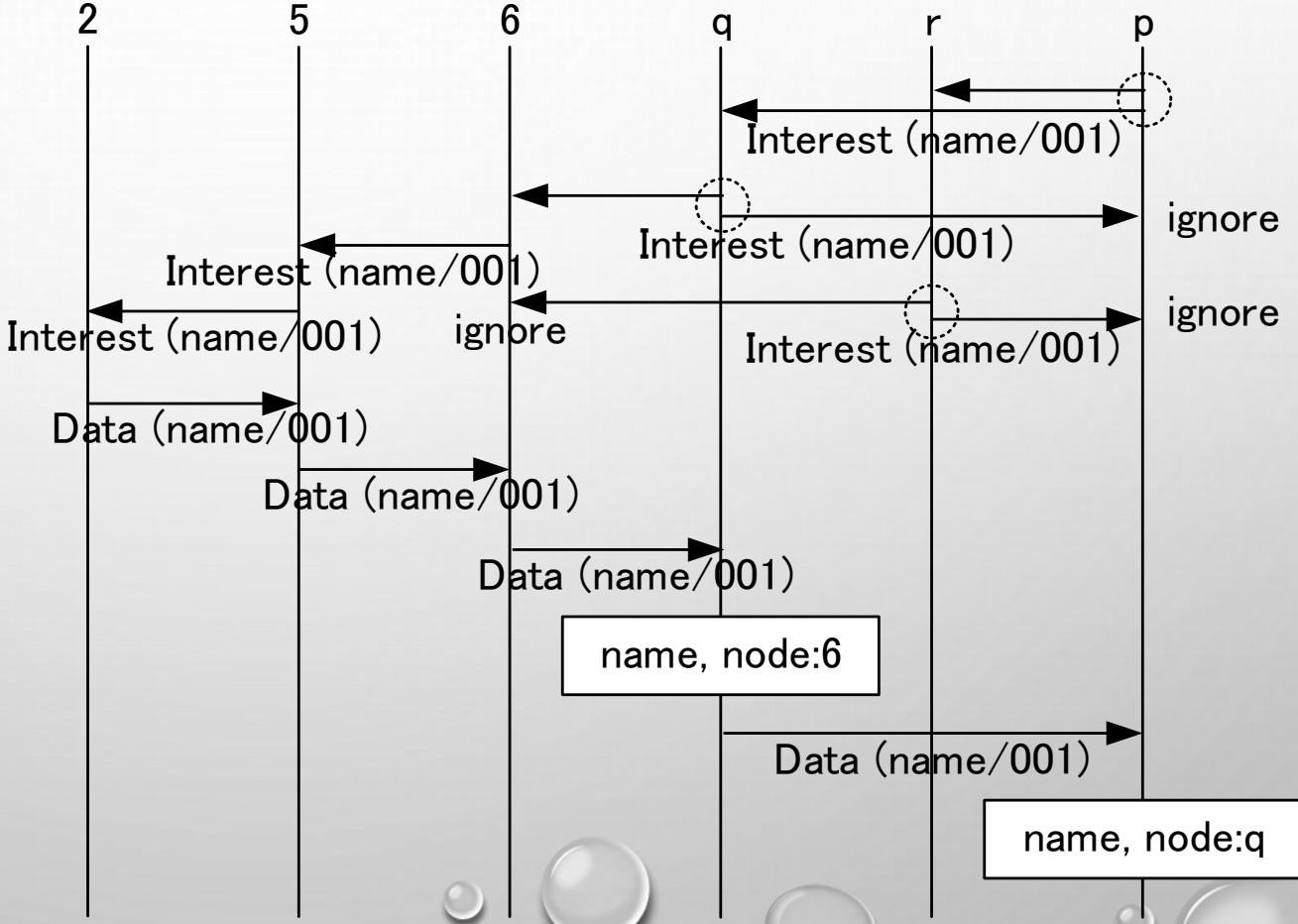
Node 2: producer

# 5. NDN ROUTING (10)
# HYBRID ROUTING APPROACH (2)

- Consumer side nodes: Only first Interest is flooded. Returning Data creates FIB entry.



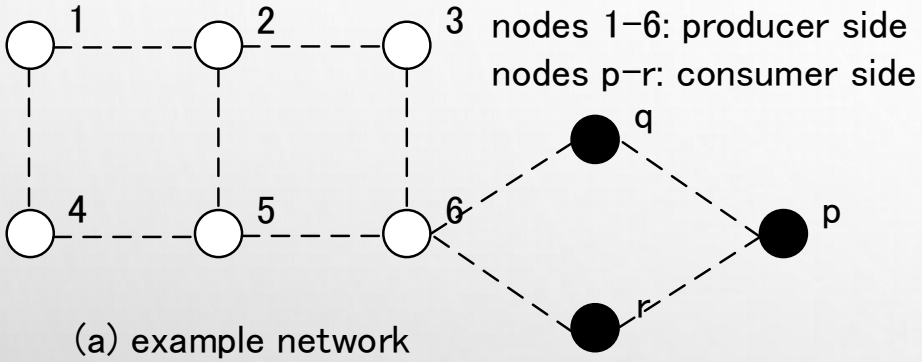

(a) example network



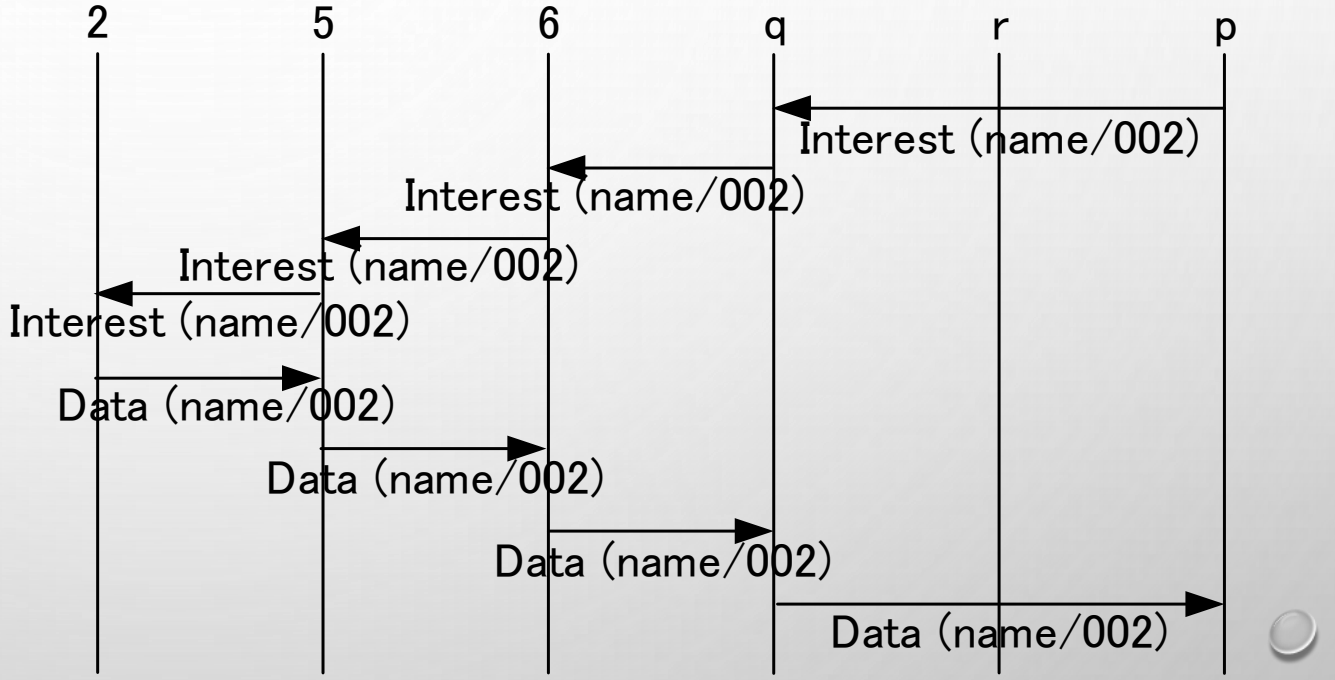

(b) communication sequence

# 5. NDN ROUTING (11)
# HYBRID ROUTING APPROACH (3)

- Consumer side nodes:  Following Interests use FIB entry.




(a) example network




(b) communication sequence

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# 6. OTHER TOPICS AND FUTURE TRENDS (1)

- Application
  - DASH (Dynamic Adaptive Streaming over HTTP) and NDN
- Security
- Caching
- NDN Router Implementation

. . . . .

- May be not so active as before ???
- Future Trends must be toward practical development.
- Replacing IP based architecture is impossible. Coexistence with IP.

# 6. OTHER TOPICS AND FUTURE TRENDS (2)

- User Identification with TLS (Transport Layer Security) and ID/Password.
- Content protection for unauthorized users, including cached ones.
  - Forward secrecy protecting withdrawn user access.
- Not all routers are not content routers. Maintaining connection among content routers.
- Name prefix advertisement among content routers.
- Data transfer between content routers must use TCP. Then coordination between TCP congestion control and NDN congestion control.

etc. etc…

- Collaboration between network operator and service provider.

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# THANK YOU FOR YOUR ATTENTION !