Adaptive Duplicate Suppression for Multicasting in a Multi-Access NDN Network

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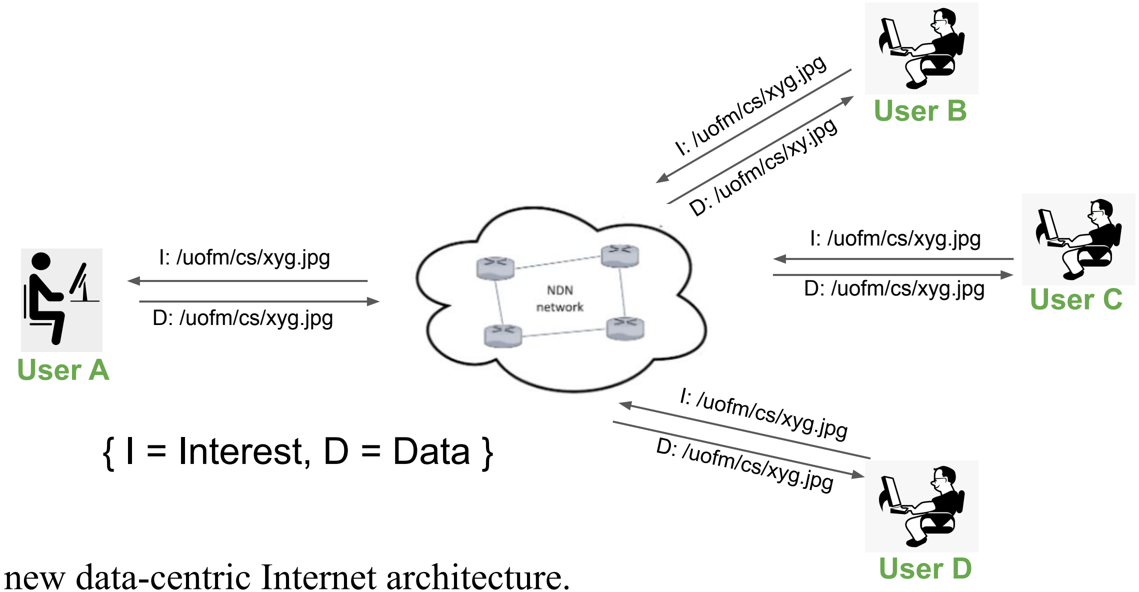
NDN Overview



Named Data Networking (NDN) is a new data-centric Internet architecture.

- **Data provenance/security:** every piece of content is named, signed, and optionally encrypted;
- **In-network caching:** packets are decoupled from the producer, can be served by any intermediate nodes with a copy;
- **Built-in multicast**: multiple data consumers can request for the same data using the same name and one only copy needs to be sent (e.g., Netflix);
- **Multi-party communication:** using data names, rather than addresses, as communication abstraction removes the need for multiple point-to-point connections.

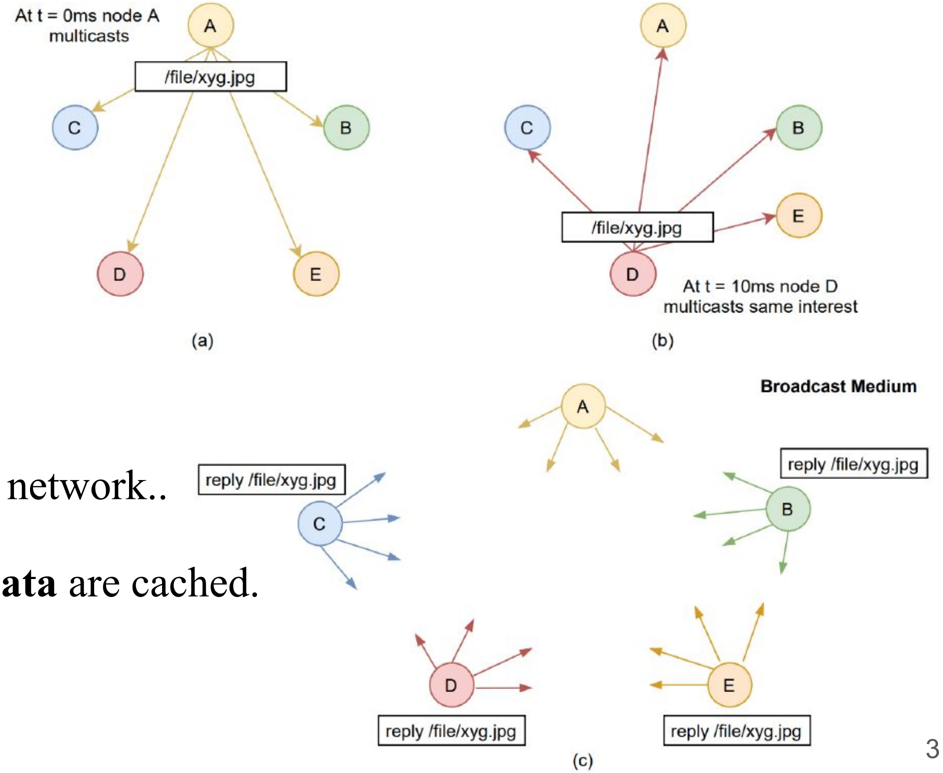
Problem

- With multi-access networks, we can run into scenarios where lots of redundant traffic flows across the network

- Node **A** floods a subnet with an Interest and shortly later (Δt) another node **D** floods the subnet with the same Interest.

- Same scenario occurs when multiple nodes multicast the same data reply over the network..

- The situation gets worse when **unsolicited data** are cached.



(a)

(b)

(c)

Motivation and Goal

On a multi-access link (e.g., WiFi or Ethernet)

1. multiple nodes may send the same Interest, i.e., request for the same data;
2. multiple nodes may respond with the same Data packet.

But current NDN design lacks a duplicate suppression mechanism → significant network congestion.

Goal

- Reduce the number of redundant requests and data replies to increase overall available bandwidth (in one-hop scenario).
- Ideally the suppression should adapt to the network condition.
    - Lossless environment: only 1 Interest/Data packet of the same name is sent by all the nodes on the same multi-access link
    - Lossy environment: allow a small number of duplicates

Existing Solutions

- Random backoff (wait) before sending Interest/Data packet [1]
  - Not adaptive to network condition

- Leader based Interest suppression [2]
  - Leader can be a bottleneck, other nodes won’t get fair chances to fetch the content

Suppression: High Level Design

Look Behind Case

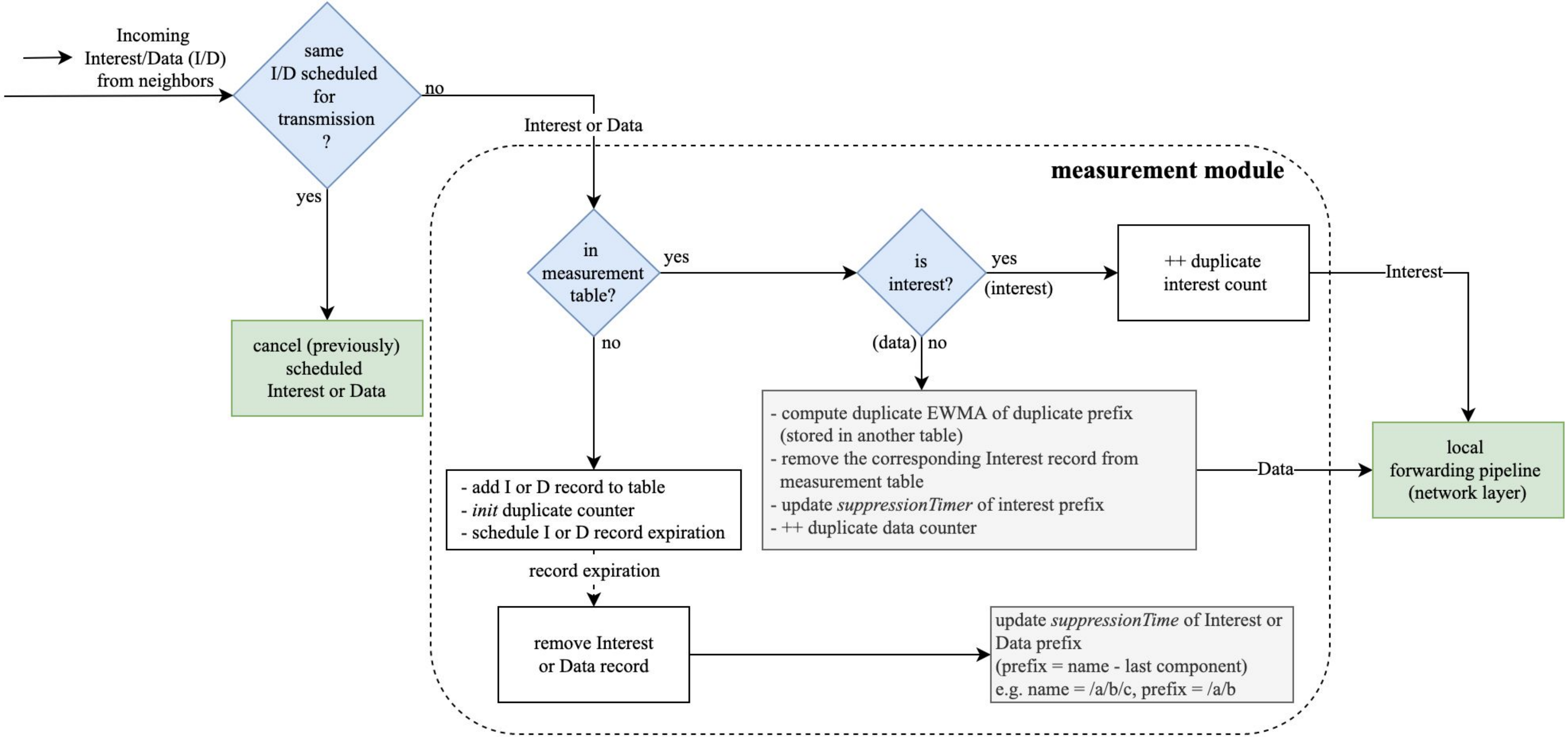
- Record all Interest/data (name, duplicate count) received from or sent to a multicast face into a measurement table
    - Every entry in the table has a short lifetime (on the order of propagation delay).
    - If Interest is satisfied or timed out, remove the Interest from the table
- Before sending an Interest/data packet to a multicast face, check to see if it is already in the table
    - If it is in the table, drop the Interest or data.
    - Otherwise, go to the “Look Ahead Case”

Suppression: High Level Design

Look Ahead Case (no record in the measurement table)

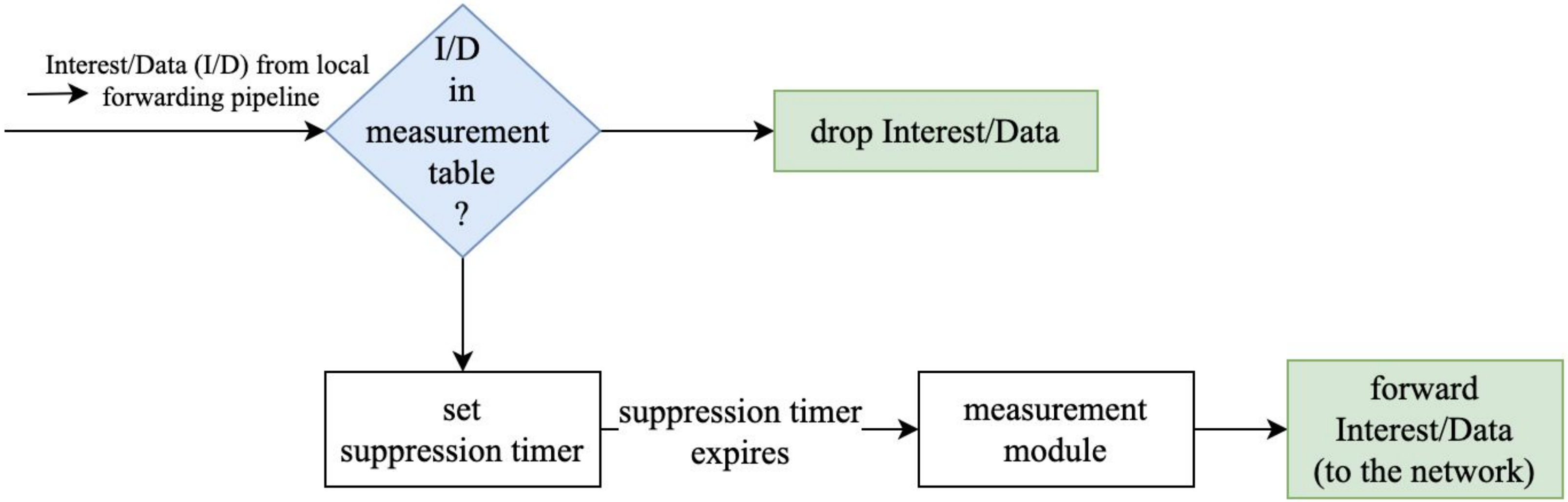
- Before forwarding an Interest/data to a multicast face, wait for some time (suppression timer)
- If another Interest/data is overheard during the wait, cancel the forwarding
- The suppression timer should be adaptive
  - **If number of duplicates is high, increase suppression timer. Otherwise, decrease the timer.**
  - For lossy links, permitting a few duplicates should be ok, so the wait time can be smaller

Incoming Interest/Data



Incoming Interest/Data (I/D) from neighbors
same I/D scheduled for transmission ?
no
yes
cancel (previously) scheduled Interest or Data
Interest or Data
measurement module
in measurement table?
yes
no
is interest?
yes
(interest)
(data)
no
++ duplicate interest count
Interest
local forwarding pipeline (network layer)
- add I or D record to table
- *init* duplicate counter
- schedule I or D record expiration
record expiration
remove Interest or Data record
- compute duplicate EWMA of duplicate prefix (stored in another table)
- remove the corresponding Interest record from measurement table
- update *suppressionTimer* of interest prefix
- ++ duplicate data counter
Data
update *suppressionTime* of Interest or Data prefix
(prefix = name - last component)
e.g. name = /a/b/c, prefix = /a/b

Outgoing Interest/Data


Interest/Data (I/D) from local
→ forwarding pipeline
I/D in measurement table ?
drop Interest/Data
set suppression timer
suppression timer expires
measurement module
forward Interest/Data (to the network)

How to update duplicate count of Interest/Data?

- Exponential Weighted Moving Average (EWMA) of the duplicate Interest/data count is computed using following formula.

$$EWMA_t = \left\{ \begin{array}{cc} dc_1 & t = 1 \\ \alpha * dc_t + (1 - \alpha) * EWMA_{t-1} & t > 1 \end{array} \right\}$$

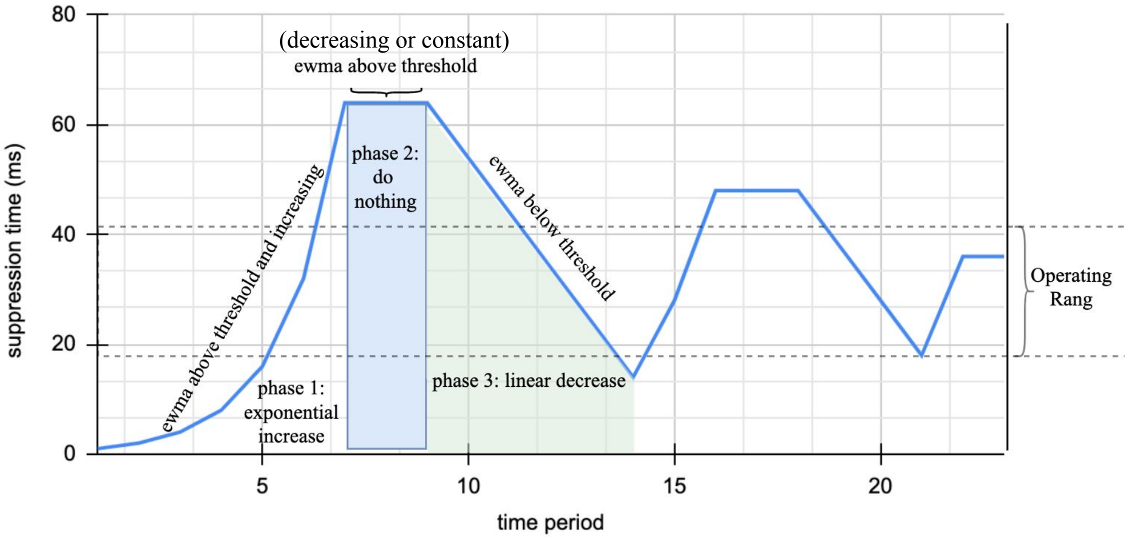
$$\alpha = smoothing\, factor,\ t = initial\ state,\ dc = duplicate\ count$$

- Granularity = name - last component, e.g. if name = */a/b*, EWMA will be of */a*
- EWMA is reset after MAX_MEASURMENT_INACTIVE_PERIOD (e.g. 5m)

How to adjustment suppression time?

Goal: Maintain the duplicate count below the DUPLICATE_THRESSHOLD (configured based on the loss rate in the environment)

- If duplicate count above threshold and increasing, **phase 1**, exponentially increase suppression time
- If duplicate count above threshold and decreasing or constant, **phase 2**, do nothing
- If duplicate count is below threshold, **phase 3**, linearly decrease suppression time



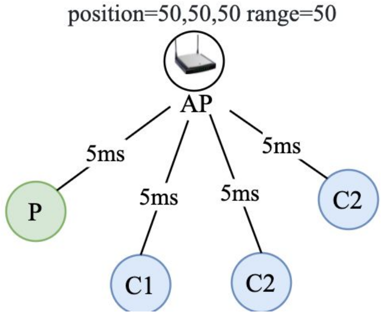
Implementation and Experiment Setup

Implemented in the current NFD @ face (link-service)
github: https://bit.ly/3pRz3Cb (work in progress)

Experiment setup

- Emulator: Mini-NDN Wifi
- Consumers simultaneously fetch 615K file (81 segments) using catchunks/putchunks over multi-access link

Topology



Experiment Constants

- SMOOTHING_FACTOR = 0.125
- MAX_MEASURMENT_INACTIVE_PERIOD = 300s
- MAX_PROPOGATION_DELAY = 15ms
- MEASURMENT_ENTRY_LIFETIME = 30ms
- DUPLICATE_THRESHOLD = 1.5
- ADATIVE_DECREASE = 4
- MULTIPLICATIVE_INCREASE = 1.3
- minSuppressionTime = 15ms (max prop delay)

Preliminary Evaluations

average number of received (↓)	w/o sup @ consumers	w/ sup @ consumers	w/o sup @ producer	w/ sup @ producer
Interest	204	90	307	135
data	225	127	0	0
unsolicited	145	47	0	0

Table A

expected number of packets from consumer & producer	(DUPLICATE_THRESHOLD = 1.5) 246 = 1.5 * (82 Interests + 82 data)
w/ suppression	262 = (135 Interests + 127 data)
w/o suppression	532 = (307 Interests + 225 data)

Table B

More than 50% duplicate traffic is suppressed by the suppression module

Preliminary Evaluations

Experiment setup

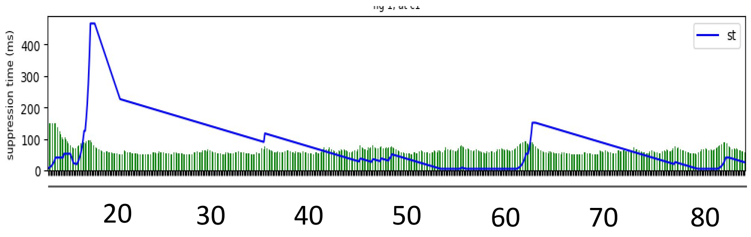
- Emulator: Mini-NDN Wifi
- Consumers simultaneously fetch 5MB file (656 segments) over multi-access link
- All other setup as same as before

	w/o suppression	w/ suppression
Goodput (Mbit/s)	5.81	6.62
Transmission time (s)	7.21	6.33
Average RTT (ms)	355.28	341.27

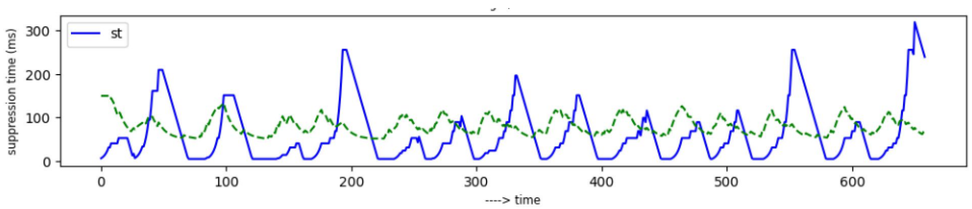
Table C: Delay metrics

Challenges

- Fluctuation of suppression time and finding a optimal operating range (experiment setup same as before)



Exp1: Transfering 615K, 81 segment file



Exp1: Transfering 5MB, ~656 segments file

- Tuning the constants and the algorithm

  ⟶ There are a few constants (SMOOTHING_FACTOR, ADATIVE_DECREASE, MULTIPLICATIVE_INCREASE, MEASURMENT_ENTRY_LIFETIME, etc) involved in this design + experiment needs to be tuned properly to obtain better results

Conclusion and Future Work

In this work,

- Designed and implemented an adaptive duplicate suppression for multicasting in a mulit-access NDN network
- Performed experiments to demonstrate the benefit of suppression module

Future Work

- Work on the current challenges, especially on tuning the constants and the algorithm
- Perform more experiments in various network conditions and sizes, and also compare other metricses such as delays -- w/ and w/o suppression
- Look in the possibility of using ML (reinforcement learning) to determining the suppression time and also to tune the constants

References

[1] Podder, Proyash, et al. “sV2Pc: On Scaling LTE-based Vehicle-to-Pedestrian Communication using NDN”

[2] Li, Menghan, et al. "Interest-suppression-based NDN live video broadcasting over wireless LAN." Frontiers of Computer Science 11.4 (2017): 675-687.

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Thank you