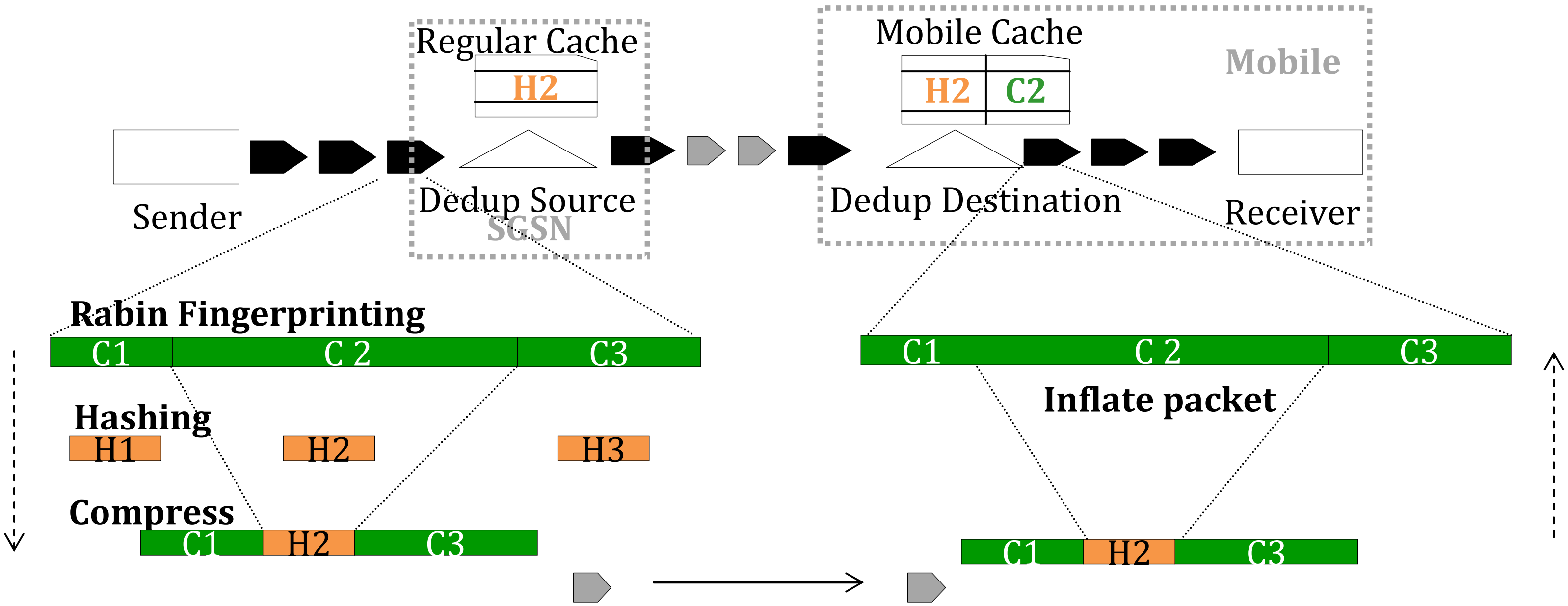
# Asymmetric Caching: Improved Network Deduplication for Mobile Devices

Shruti Sanadhya,[1] Raghupathy Sivakumar,[1] Kyu-Han Kim,[2]
Paul Congdon,[2] Sriram Lakshmanan,[1] Jatinder P Singh[3]

[1]Georgia Institute of Technology, Atlanta, GA, USA
[2]HP Labs, Palo Alto, CA, USA [3]Xerox PARC, Palo Alto, CA, USA

# Introduction

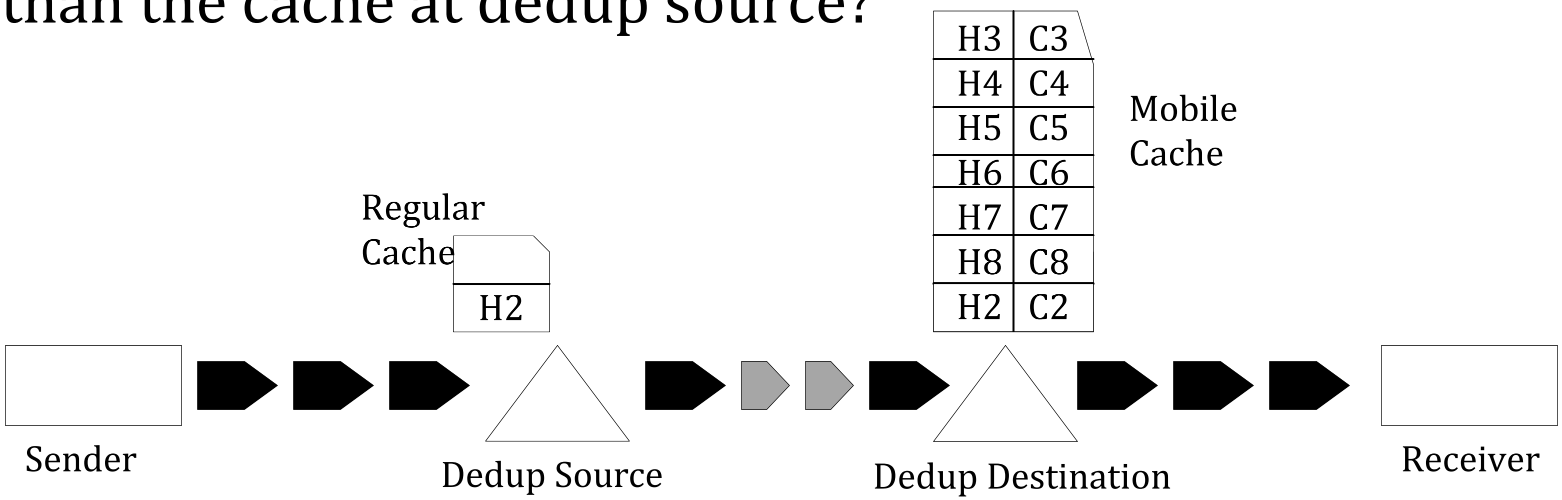
- Network traffic has a lot of redundancy
  - 20% HTTP content accessed on smartphones is redundant[1]
- Network deduplication (dedup) leverages this redundancy to conserve network bandwidth




[1] Qian *et al*,, "Web Caching on Smartphones: Ideal vs. Reality " , MobiSys 2012

# The Asymmetry Problem

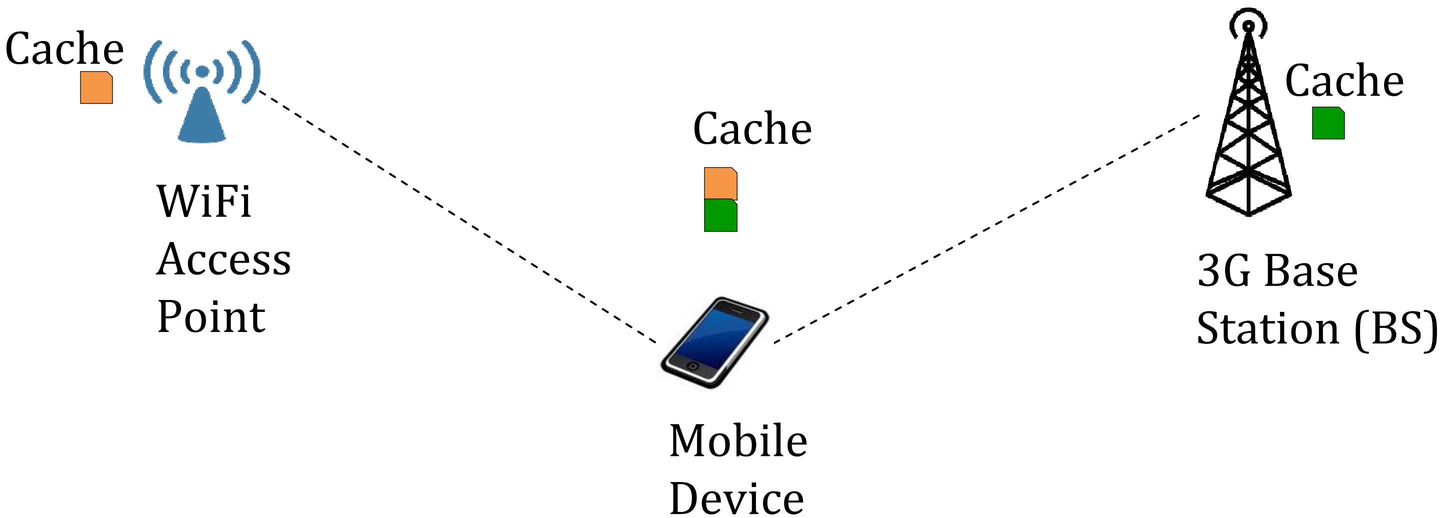
- What happens when the mobile cache is more populated than the cache at dedup source?




***How can all the past cached information at the mobile be successfully leveraged for dedup by any given dedup source?***

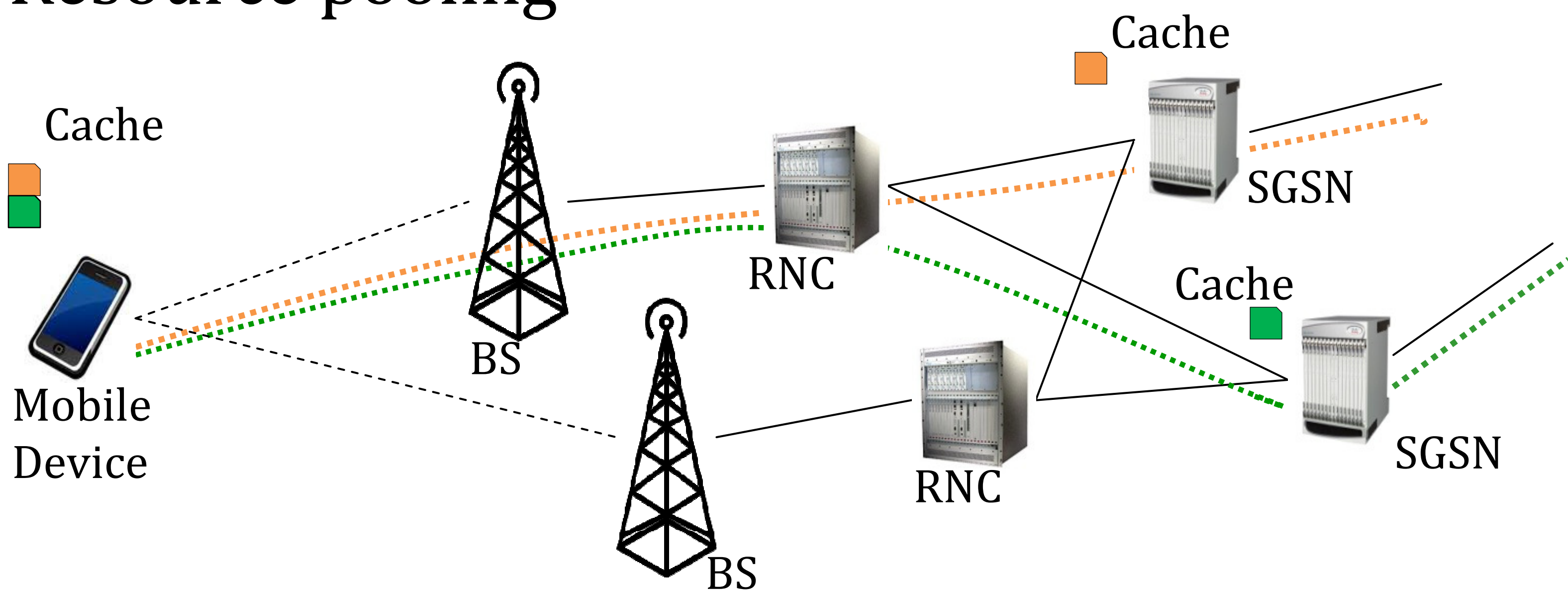
# Motivational Scenarios

- Multi-homed devices



# Motivational Scenarios

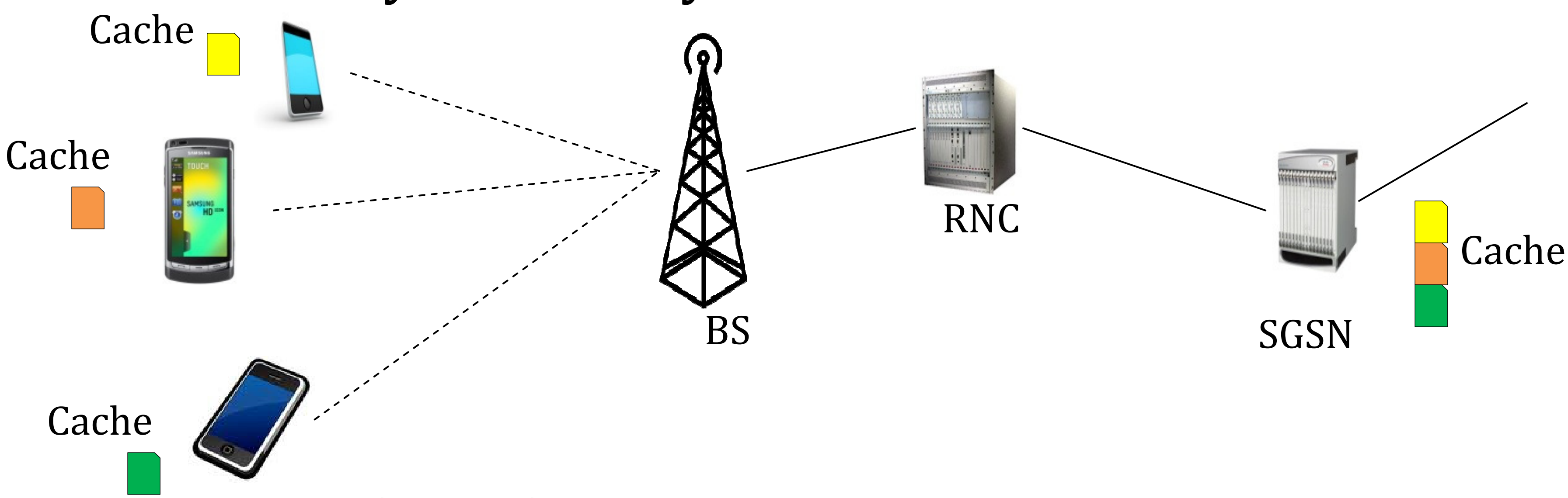
- Multi-homed devices
- Resource pooling




- BS: Base Station
- RNC: Radio Network Controller
- SGSN: Serving GPRS Support Node

# Motivational Scenarios

- Multi-homed devices
- Resource pooling
- Memory scalability



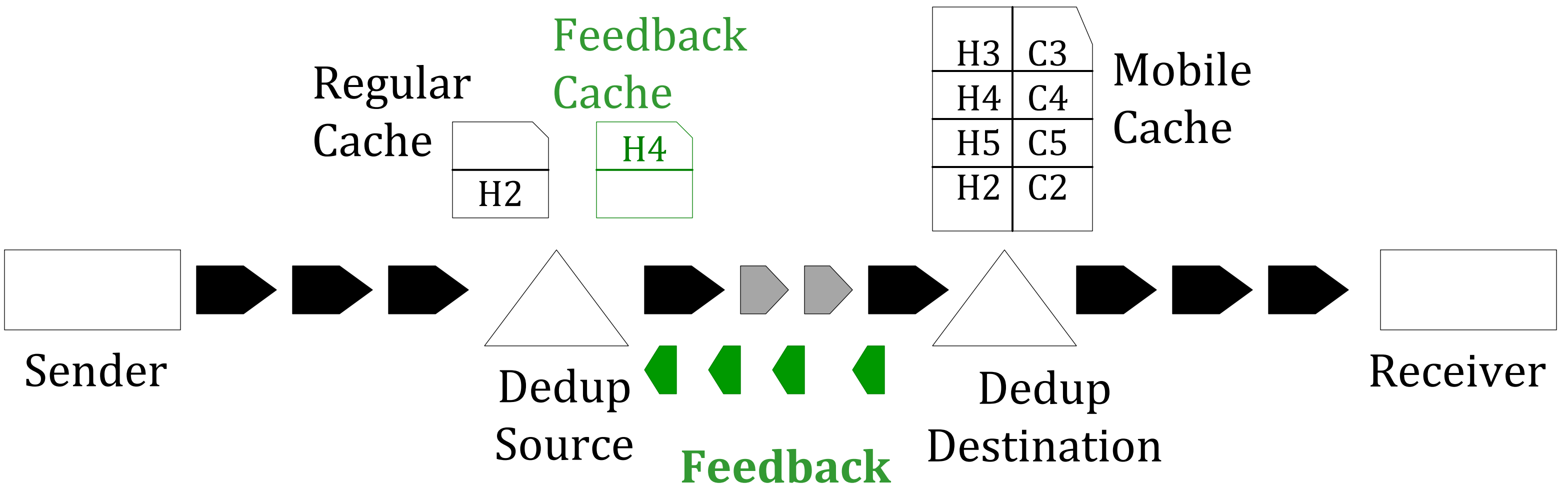

  - BS: Base Station
  - RNC: Radio Network Controller
  - SGSN: Serving GPRS Support Node

# Scope and Goals

- Scope
  - Laptops/smartphones using 3G/WiFi
  - Conserving cellular bandwidth
  - Downstream and unencrypted traffic

- Goals
  - Overall efficiency: Using downstream *and* upstream more efficiently
  - Application agnostic: Applicable to any application
  - Limited overheads: Deployable computational and memory complexities

# Asymmetric Caching - Overview




- Mobile cache is more populated than dedup source
- On receiving downstream traffic, the mobile selectively advertises portions of its cache to dedup source
- Dedup source also maintains a *feedback cache*
- Both *regular and feedback cache* is used for dedup

# When is feedback sent?

- Feedback is sent *reactively*
- Feedback is sent only when there is downstream traffic
- Feedback sent is specific to the ongoing traffic

# Where from is feedback selected?

- Hashes at dedup destination can be organized as per:
  - Order of arrival

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| H1 | H2 | **H3** | **H4** | **H5** | H6 | H7 | H8 | **H9** | **H10** |

  - Same flow
    (Src IP, Dest IP, Src Port, Dest Port )

| | | | | |
|---|---|---|---|---|
| H1 | H2 | H6 | H7 | H8 |
| **H3** | **H4** | **H5** | **H9** | **H10** |

  - Same object
    (HTML , JPEG or CSS)

| | | |
|---|---|---|
| H1 | H2 | |
| H6 | H7 | H8 |
| **H3** | **H4** | **H5** |
| **H9** | **H10** | |

- Objects help in effectively matching new and old content
- Application agnostic estimate of objects are *flowlets*

# How are flowlets extracted?

- Sequence of bytes in a flow is a time-series
- *Flowlets* are piecewise stationary segments of a flow
- Check for flowlet boundary at start of each packet
- Consider byte series $B_{[0:m]}$(1st packet), $B_{[m+1:n]}$ (2nd packet) and $B_{[0:n]}$ as autoregressive processes of order *p*:

  $$\underbrace{\overbrace{B_0, B_1, \ldots, B_m}^{B_{[0:m]}}, \overbrace{B_{m+1}, \ldots, B_n}^{B_{[m+1:n]}}}_{B_{[0:n]}}$$

  $B_i = \Sigma_{1<=j<=p}\, a_i B_{i-j} + \sigma\varepsilon$ , $\varepsilon$ is white noise

- $d_{[0:m:n]} = gain(B_{[0:n]}) - gain(B_{[0:m]}) - gain(B_{[m+1:n]})$

  Gain in the noise power when $B_{[0:n]}$ is in one flowlet instead of different flowlets: $B_{[0:m]}$ and $B_{[m+1:n]}$
- If $d_{[0:m:n]} > d_{thresh}$ , then flowlet boundary exists at *m*

# How is feedback selected?

- Find best matching past flowlet

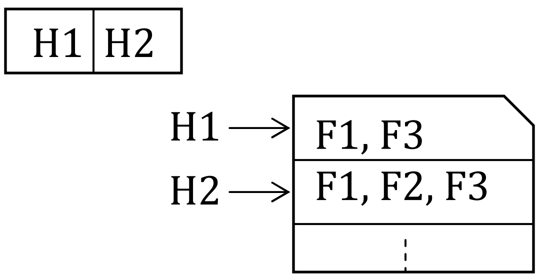
# How is feedback selected?

- Find best matching past flowlet

| H1 | H2 |
|---|---|

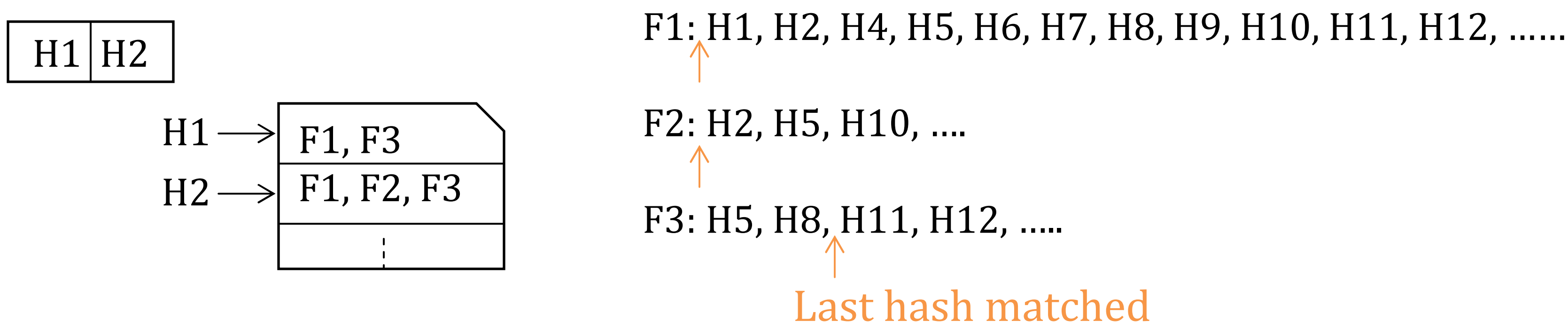
# How is feedback selected?

- Find best matching past flowlet



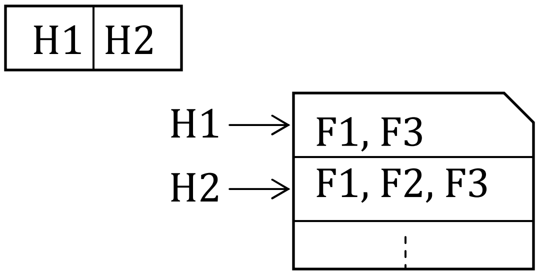
# How is feedback selected?

- Find best matching past flowlet



# How is feedback selected?

- Find best matching past flowlet




F1: H1, H2, H4, H5, H6, H7, H8, H9, H10, H11, H12, …….

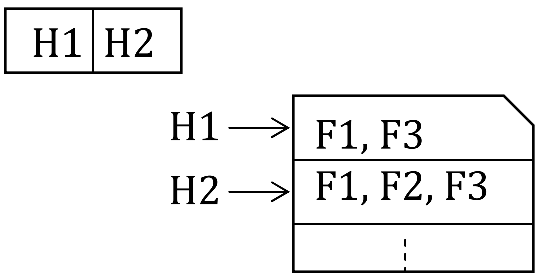
F2: H2, H5, H10, ….

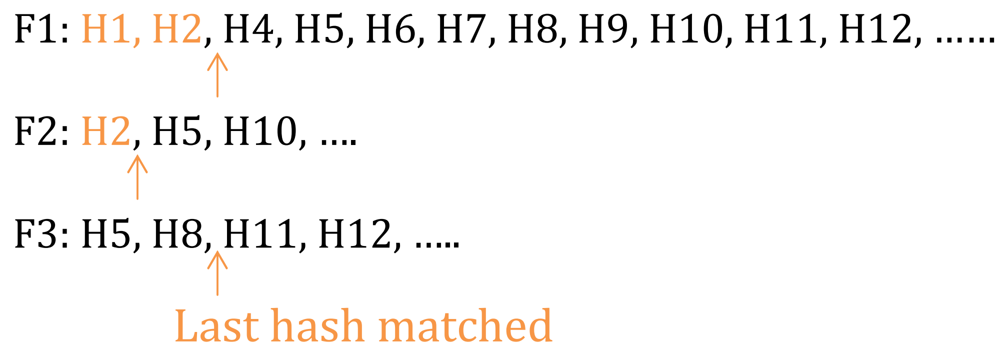
F3: H5, H8, H11, H12, …..

Last hash matched

# How is feedback selected?

- Find best matching past flowlet

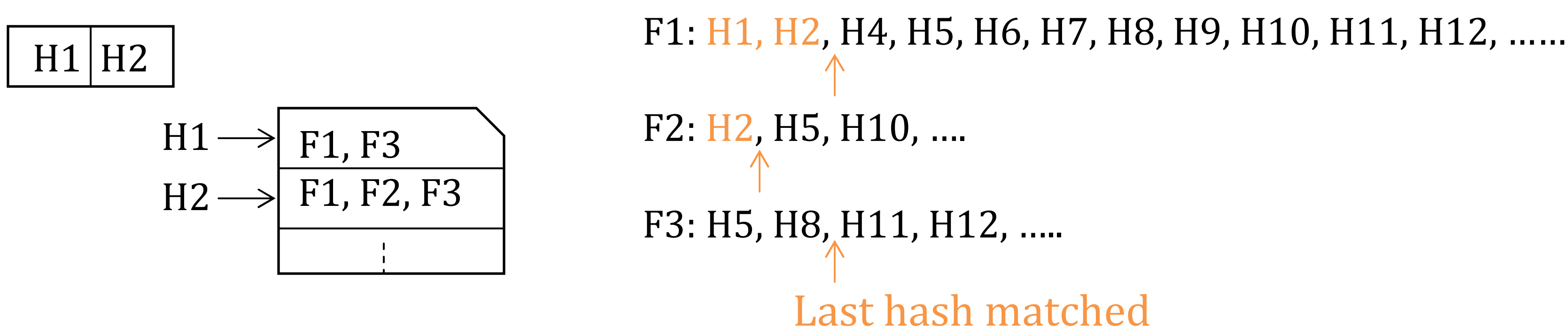



  - *Flowlet 1* (F1) is best matched

# How is feedback selected?

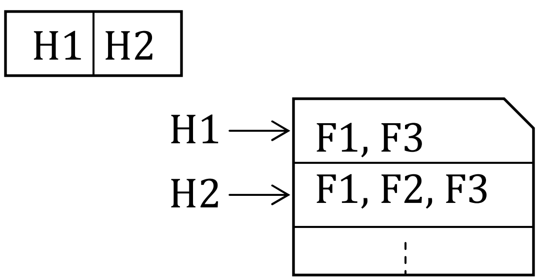
- Find best matching past flowlet




  - *Flowlet 1* (F1) is best matched
- Find start of next feedback in the best matching flowlet

# How is feedback selected?

- Find best matching past flowlet




F1: H1, H2, H4, H5, H6, H7, H8, H9, H10, H11, H12, …….

F2: H2, H5, H10, ….

F3: H5, H8, H11, H12, …..

Last hash matched

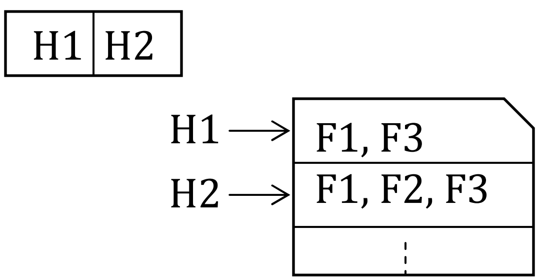
  - *Flowlet 1* (F1) is best matched

- Find start of next feedback in the best matching flowlet

*Best matching past flowlet* **H1, H2, H4, H5, H6, H7, H8, H9, H10, H11, H12, H13, – – –**

# How is feedback selected?

- Find best matching past flowlet




F1: H1, H2, H4, H5, H6, H7, H8, H9, H10, H11, H12, …….

F2: H2, H5, H10, ….

F3: H5, H8, H11, H12, …..

Last hash matched

  – *Flowlet 1* (F1) is best matched

- Find start of next feedback in the best matching flowlet

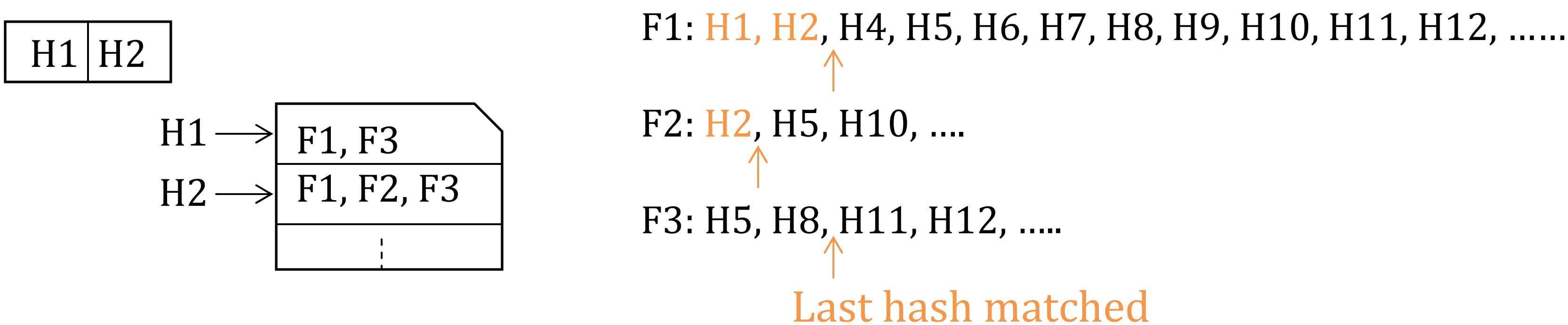
*Best matching past flowlet*

**H1, H2, H4, H5, H6, H7, H8, H9, H10, H11, H12, H13, – – –**

Last hash matched

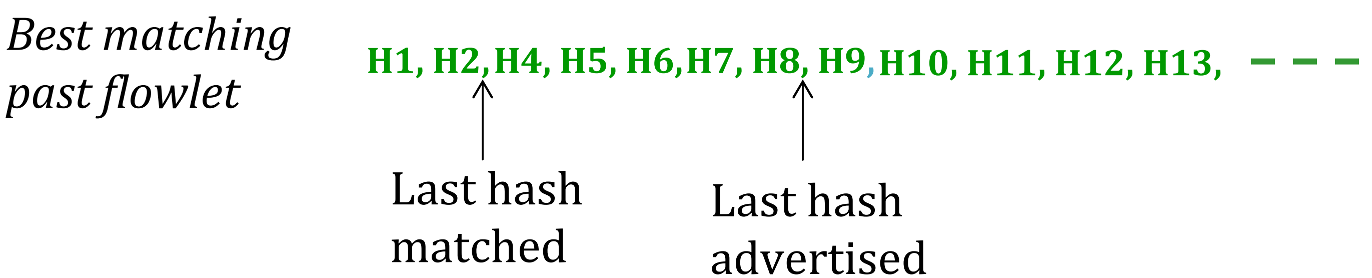
# How is feedback selected?

- Find best matching past flowlet



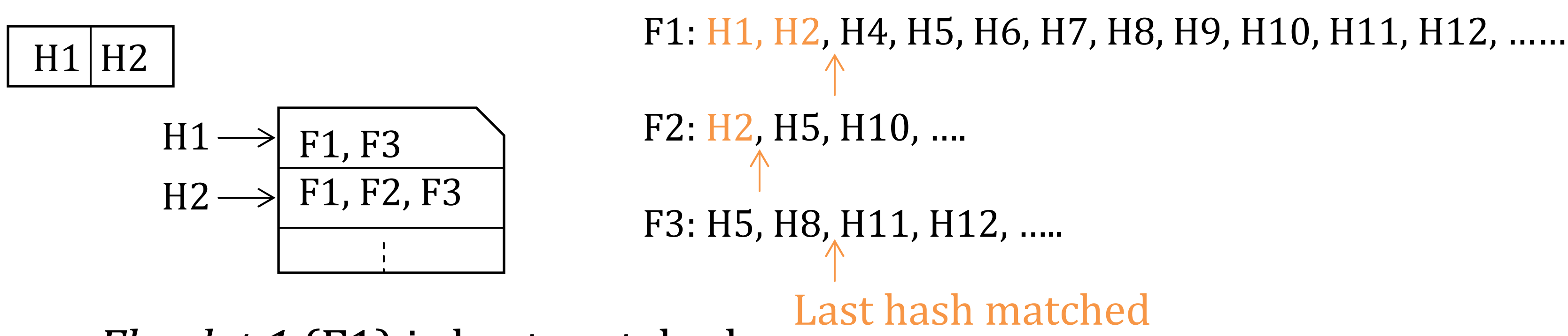

  - *Flowlet 1* (F1) is best matched

- Find start of next feedback in the best matching flowlet



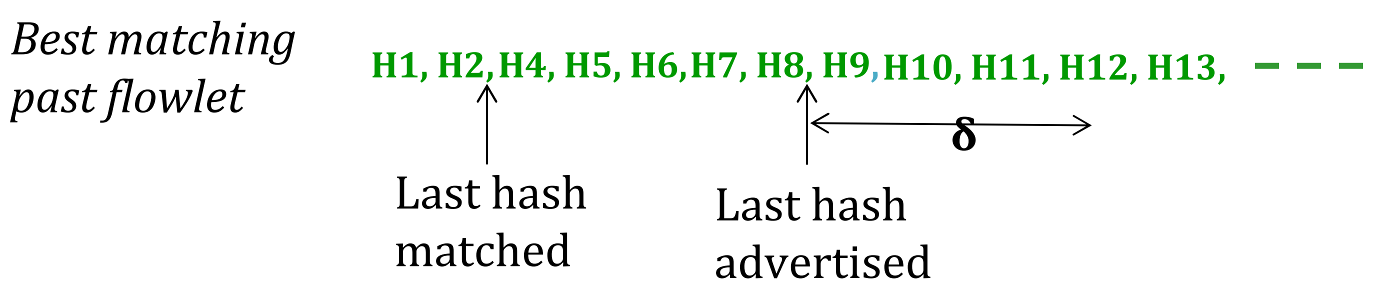
# How is feedback selected?

- Find best matching past flowlet




  – *Flowlet 1* (F1) is best matched

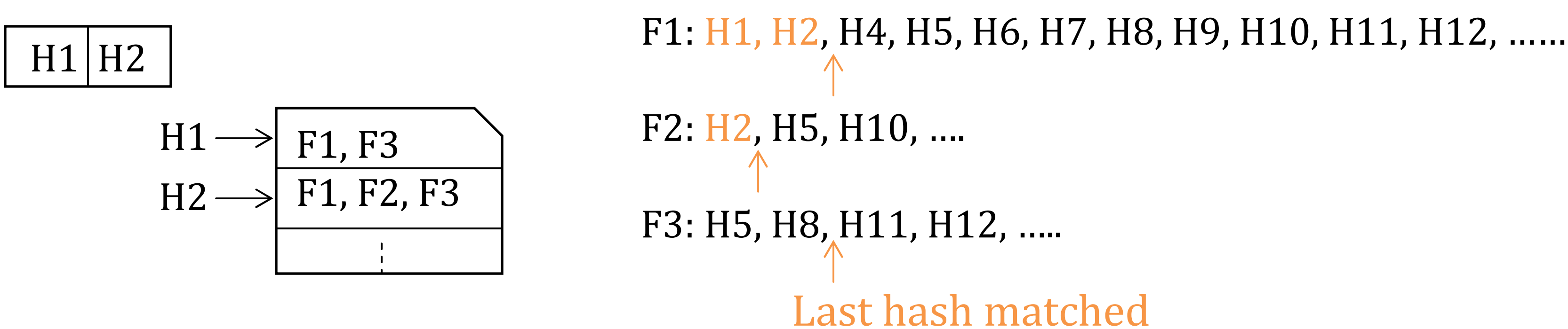
- Find start of next feedback in the best matching flowlet




  – δ : temporal offset

# How is feedback selected?

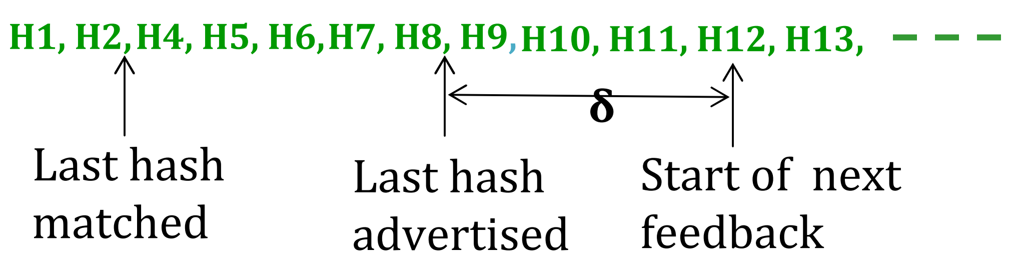
- Find best matching past flowlet




  - *Flowlet 1* (F1) is best matched

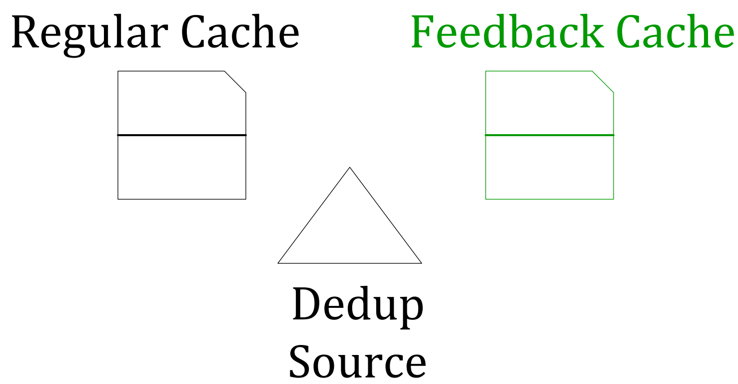
- Find start of next feedback in the best matching flowlet

*Best matching past flowlet*



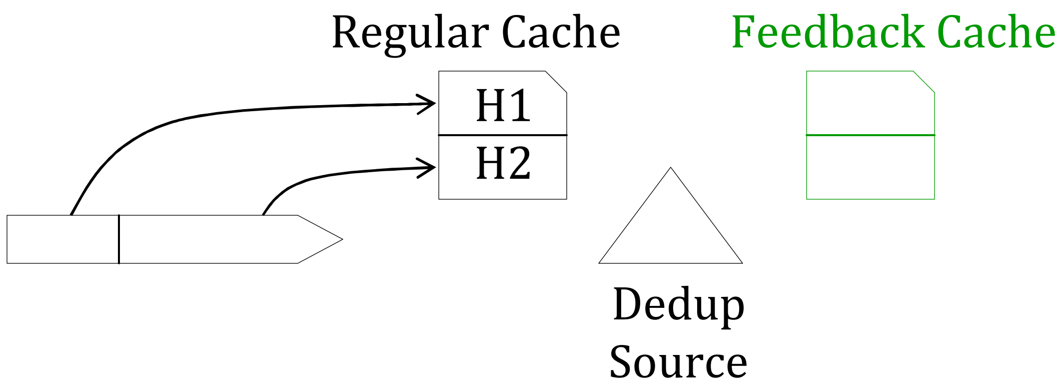

  - δ : temporal offset

# How is the feedback used?



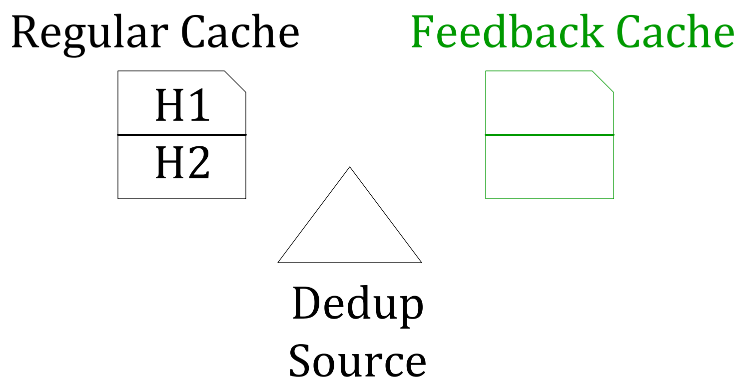

- Dedup source maintains a *feedback cache* along with *regular cache* of baseline dedup

# How is the feedback used?



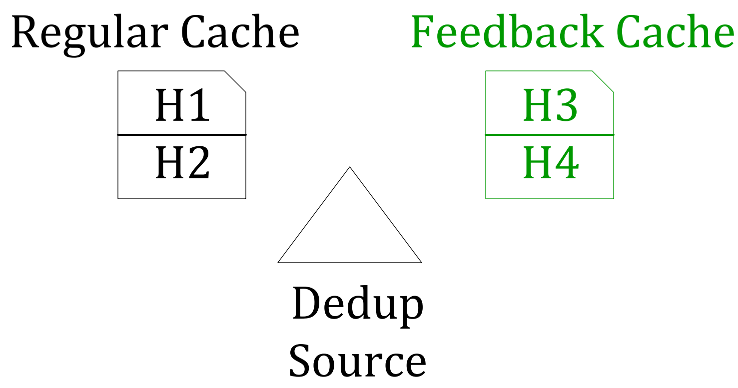

- Dedup source maintains a *feedback cache* along with *regular cache* of baseline dedup
- Regular cache is populated by downstream data

# How is the feedback used?



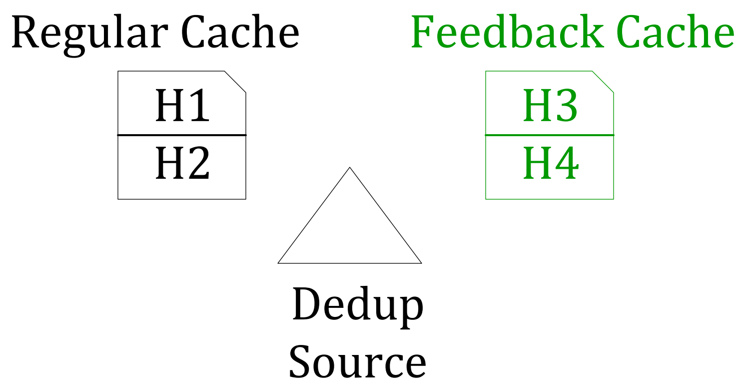

- Dedup source maintains a *feedback cache* along with *regular cache* of baseline dedup
- Regular cache is populated by downstream data

# How is the feedback used?




- Dedup source maintains a *feedback cache* along with *regular cache* of baseline dedup
- Regular cache is populated by downstream data
- Feedback hashes are inserted in *feedback cache*

# How is the feedback used?




- Dedup source maintains a *feedback cache* along with *regular cache* of baseline dedup
- Regular cache is populated by downstream data
- Feedback hashes are inserted in *feedback cache*

  Every downstream packet is deduped using both *regular* and *feedback cache*

# Design Summary

- When is the feedback sent?
- Reactively
- Where from is the feedback chosen?
- Flowlets at dedup destination
- How are flowlets extracted?
- Stationarity properties
- How is the feedback selected?
- Best matching flowlet and pointers in past flowlet
- How is the feedback used?
- Stored in the feedback cache for dedup

# Trace Based Analysis

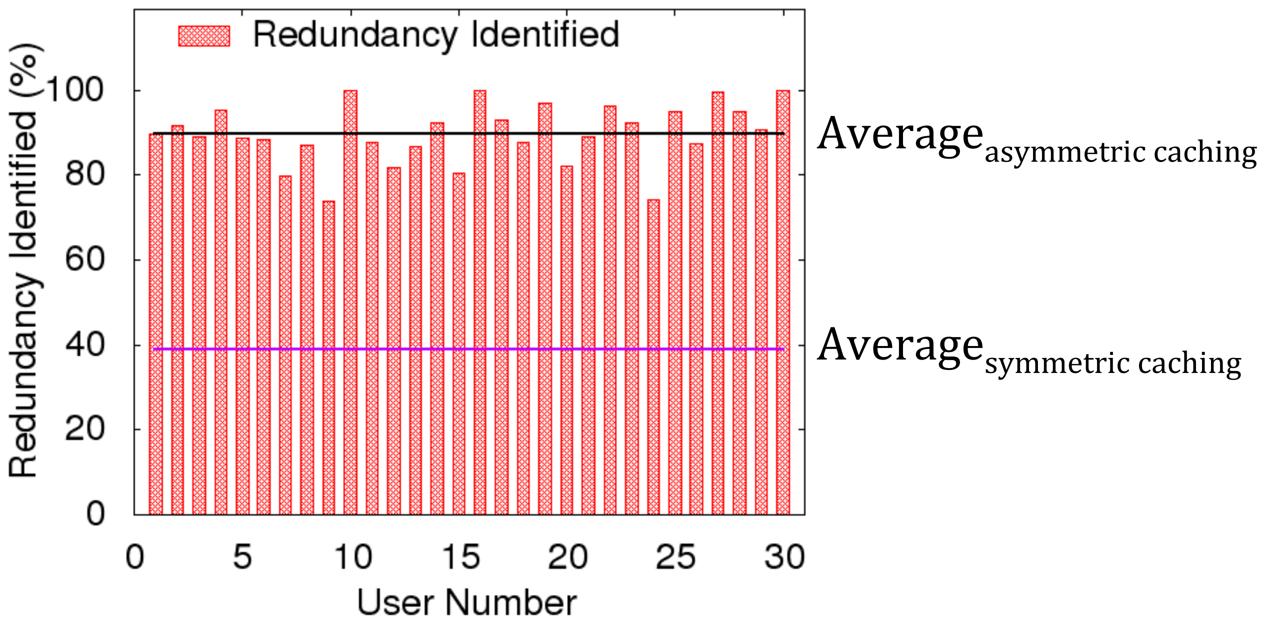
- Data collection
  - 25 laptop and 5 smartphone users over 3 months giving 26GB of unsecured downlink data
  - WiFi as well as 3G network
  - Packet sniffing through Wireshark and Tcpdump

- Trace analysis
  - Custom analyzer implemented in Python
  - Mimic mobility by splitting trace into two halves: *past* and *present*
  - *Past* trace populates the initial cache at the dedup destination This is the data remembered from previous networks access
  - 30 random connections from the *present* create ongoing traffic
  - Dedup is performed using asymmetric caching

# Trace Analysis Results - I

- Redundancy identified

$$\frac{\textit{\# Redundant bytes found by asymmetric caching}}{\textit{Actual \# redundant bytes}} \times 100$$



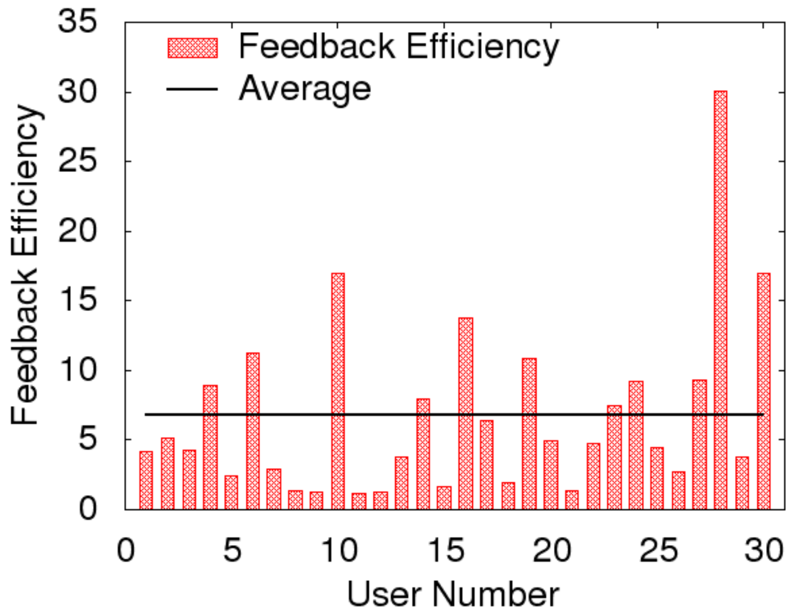

*Asymmetric caching leverages significant portion of the achievable redundancy*

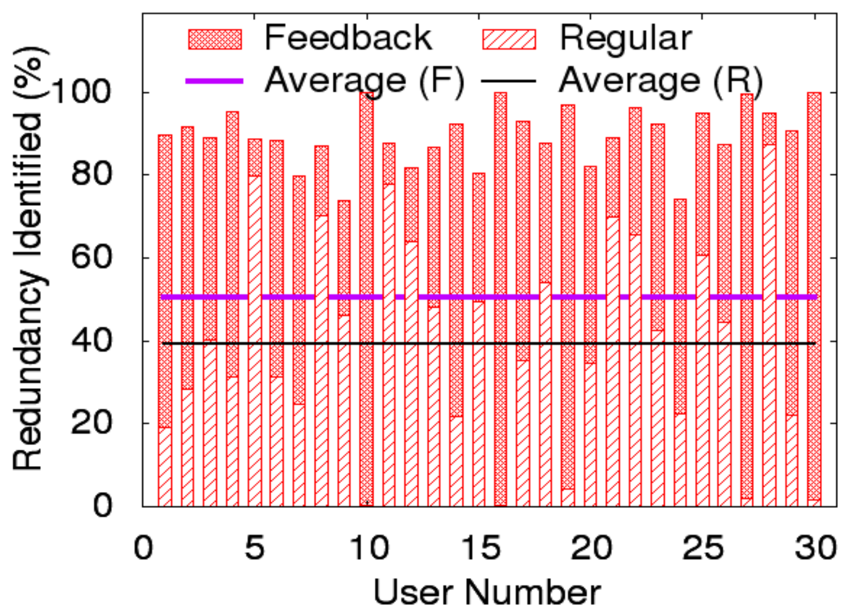
# Trace Analysis Results - II

- Feedback efficiency

$$\frac{\textit{\# Bytes saved downstream}}{\textit{\# Bytes sent upstream}}$$

*Split of total hits across the caches at dedup source*




*Asymmetric caching generates efficient and relevant feedback*



Georgia Institute of Technology

GNAN Research Group

# Related Work

- Network layer approaches
  - Spring *et al*, "A protocol-independent technique for eliminating redundant network traffic". *SIGCOMM, 2000.*
  - Aggarwal *et al*, "EndRE: an end-system redundancy elimination service for enterprises". *NSDI, 2010.*
  - Shen *et al,* "REfactor-ing content overhearing to improve wireless performance". *MobiCom, 2011*
- Transport layer approaches
  - Zohar *et al*, "The power of prediction: cloud bandwidth and cost reduction", *SIGCOMM 2011*
- Application layer approaches
  - Web browser caches and proxies
  - Content Distribution Networks (CDNs)

# Conclusion and Future Work

- A dedup strategy that leverages past remembered on mobile devices to perform dedup at any dedup source
- Application agnostically estimate different objects in a flow by using stationarity properties of different content
- Trace analysis of 30 users shows that asymmetric caching:
  - Leverages 89% of achievable redundancy
  - Gives 6x feedback efficiency
- Prototype implementation on Linux desktop and Android smartphone with deployable overheads
- Future Work:
  - Upstream dedup, i.e. reduce redundant content sent upstream
  - Extending dedup to end-to-end encrypted traffic
  - Study energy impact of asymmetric caching on mobile devices

# Questions?