A hybrid overlay multicast and caching scheme for information-centric networking

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Outline

- Motivation
- Design objectives
- MultiCache architecture
  - Functionality overview
- Protocols
  - Multicast
  - Caching
- Performance evaluation
- Conclusions & Future work

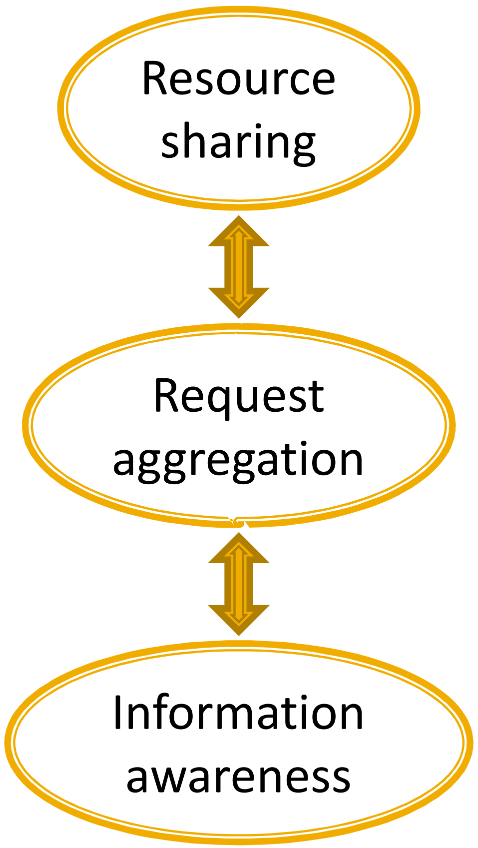
Motivation

- Internet model: end-to-end principle
  - Need to resolve a specific end-host to retrieve data
- Internet use: information-centric
  - "Anyone" that can provide the required data is fine
    - E.g. P2P, cloud computing, etc.
- Arbitrary overlay content delivery structures, ignoring:
  - Network topology
  - Data location
  - Data popularity
- Inefficient use of network resources
  - E.g. 70% percent of an AS ingress traffic could be avoided in BitTorrent[1]

[1] T. Karagiannis, P. Rodriguez, and K. Papagiannaki, "Should internet service providers fear peer-assisted content distribution?" in Proc. Of the Internet Measurement Conference, 2005, pp. 63–76.

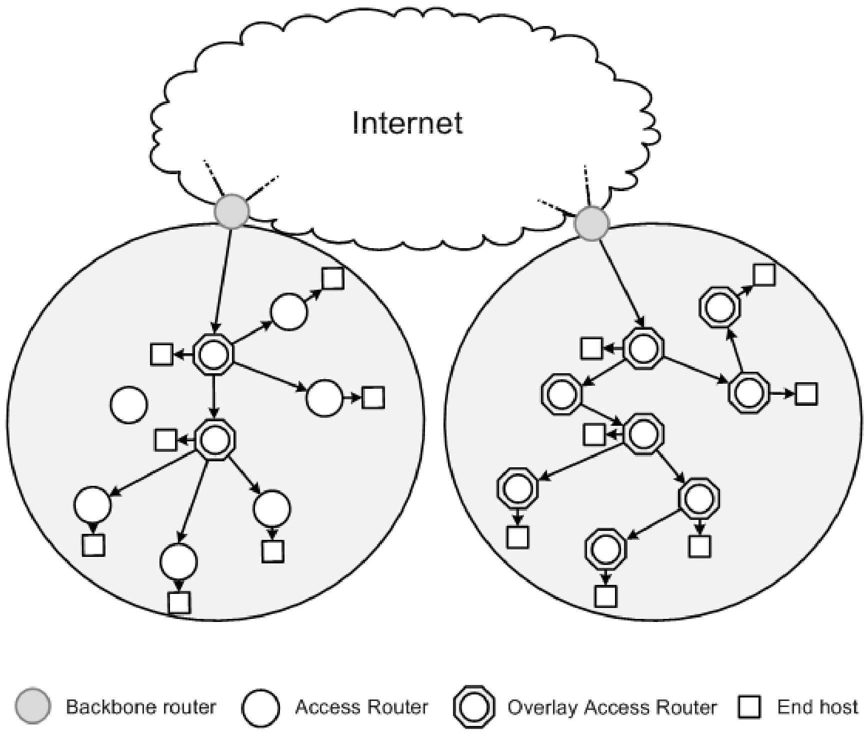
Design objectives

- Efficient use of network resources
  - Resource sharing mechanisms: multicast, caching
- Scalability
  - Unlimited size of the information domain
- Usage model simplification
  - End hosts not engaging in translating *what* to *where*
- Facilitated deployment of new functionality
  - Clean-slate requires replacing existing functionality
    - E.g. ICT FP7 PSIRP Project
  - Network layer available solutions (e.g., IP Multicast)
    - Practically not available
    - Not easy to deploy gradually
    - Difficult group management
  - Targeting at an overlay architecture…



MultiCache architecture

- Overlay Access Routers (OARs)
  - Deployed inside access networks
  - Gradual deployment is feasible
- Providing overlay multicast
  - Based on Scribe over Pastry
    - Scalable
    - Adaptive to physical topology
- Acting as caches
  - Multiple cache locations
  - Close to end-hosts

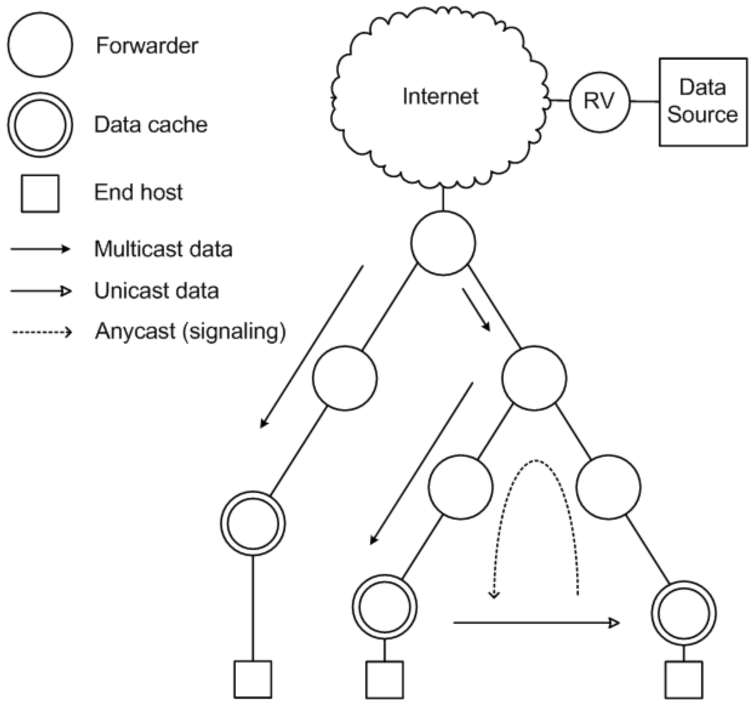


- Proxy-ing end host access to the information aware overlay
  - Facilitating group management
  - Proxy OAR designated during network attachment

MultiCache

Functionality Overview

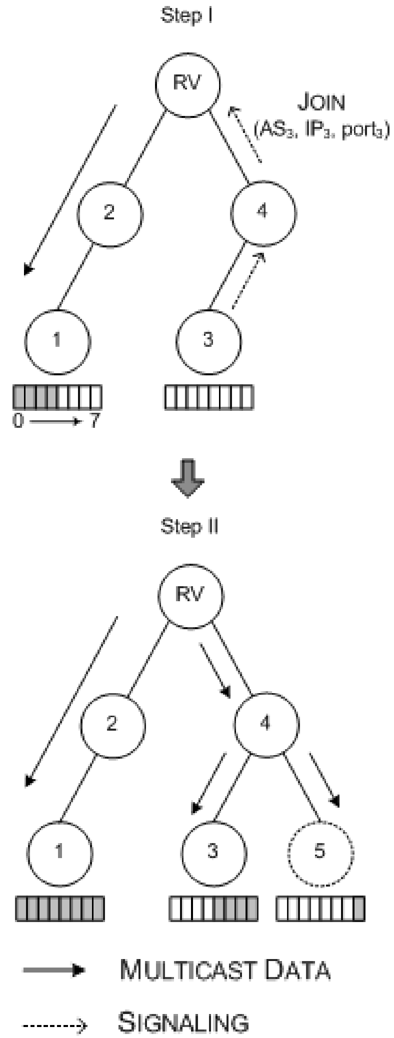
- Currently focusing on content distribution
- Overlay multicast brings content from its origin
- Caching:
  - Data @ proxy OARs, i.e., multicast tree leafs
  - Forwarding state @ Forwarding OARs
- Anycasting cache requests
  - Correlating forwarding state with data availability
  - Localizing traffic inside sub-trees
- Unicasting cached data
  - Reducing stretch…
- Content fragmentation
  - Piece level
    - Parallelizing transfers
    - Enabling partial caching
  - Block level
    - Facilitating cache provision…



MultiCache

Multicast

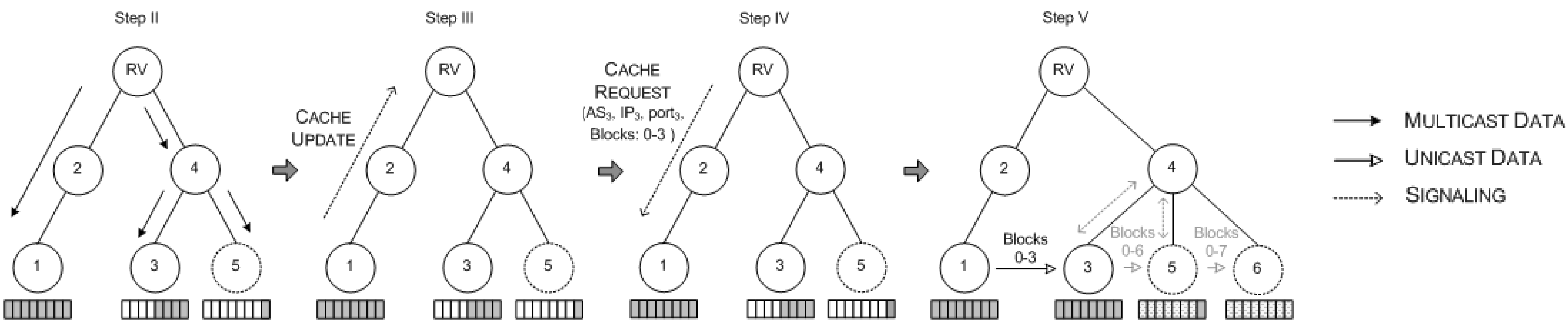
- Publisher advertizes data to RV point(s)
- OARs subscribe to data
  - Possibly aggregating end host requests
  - Scribe JOIN messages extended with joining OAR information:
    - IP address, listening port, 32-bit AS number
    - Later used for cache provision
- Subject to arrival time, requests served with:
  - Multicast from the source
  - Unicast from a near-by/local cache
- JOIN suppressing OARs: *meta-cache* OARs
  - Store joining OAR information
  - Keep track of forwarded data



MultiCache

Caching

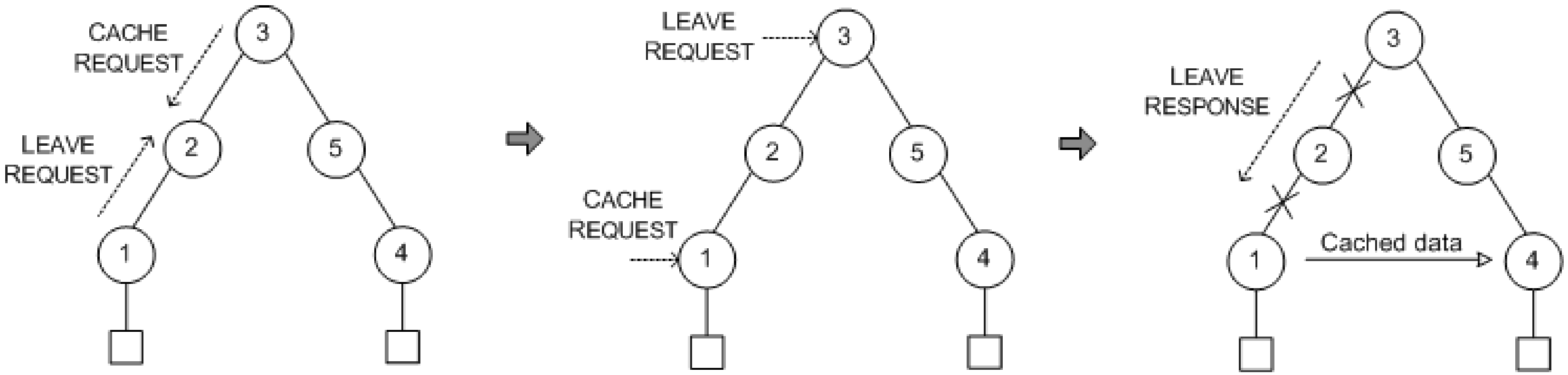
- Cache availability signaled to ancestors (CACHE UPDATE)
  - Suppressed at the first OAR already aware of another cache (or the RV)
- Cache request issued by meta-cache OARs (CACHE REQUEST)
  - Anycast towards rest of the children
  - Preferably selecting a child in the same AS with the new subscriber
- Cached data sent to requesting OAR via unicast
  - Also contributing to cache creation



MultiCache

Cache replacement: signaling

- Multicast tree participation correlated with data availability
  - Evicting forwarding state before data
  - Avoiding cache misses: either cached data or multicast
- Scribe's *Leave* procedure altered
  - Tree branches torn down on response from highest non leaving ancestor
  - Cache requests for items pending for eviction served normally
- Incoming requests buffered until cache space available



MultiCache

Cache replacement: policies

- Common policies
  - Least Recently Used (LRU)
    - Evicting the LRU fragment of the LRU file
- MultiCache specific policies
  - Most Recently Used - Intra Domain (MRU-Intra)
    - Evicting the fragment most recently delivered to an OAR *k* of the same domain
    - Increased probability of the fragment not evicted by OAR *k*
  - Most Frequently Used - Intra Domain (MFU-Intra)
    - Evicting the fragment most frequently delivered to OARs of the same domain
    - Increased probability for an alternative caching location to exist
- MRU/MFU – Intra enforced on fragments
  - Fragments not associated with files
  - No control signaling and state overhead

Performance evaluation

Workload and metrics

- Simulation based evaluation
- GT-ITM topologies
- BitTorrent-like workload
  - Mandelbrot-Zipf distribution of file popularity [1]
  - Exponential decay arrival process for file requests [2]
  - Fixed *file* arrival rate [2]
  - Trace sampled file sizes
- Metrics
  - Cache hit ratio (CHR) (%)
  - Intra-domain cache hit ratio (CHR - Intra) (%)
  - Distance to block source

[1] M. Hefeeda and O. Saleh, "Traffic modeling and proportional partial caching for peer-to-peer systems," *IEEE/ACM Transactions on Networking*, vol. 16, no. 6, pp. 1447–1460, 2008.

[2] L. Guo, S. Chen, Z. Xiao, E. Tan, X. Ding, and X. Zhang, "A performance study of BitTorrent-like peer-to-peer systems," *IEEE JSAC*, vol. 25, no. 1, pp. 155–169, 2007.

Performance evaluation
Important parameters

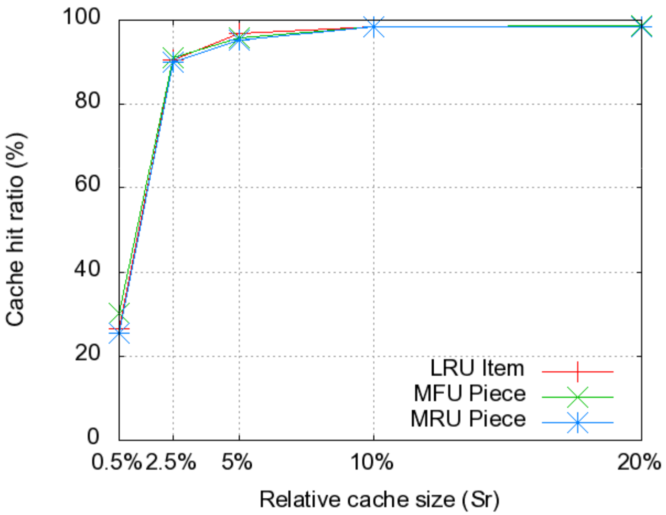
- Relative Cache Size, S_r
  - Percentage of "infinite cache size "

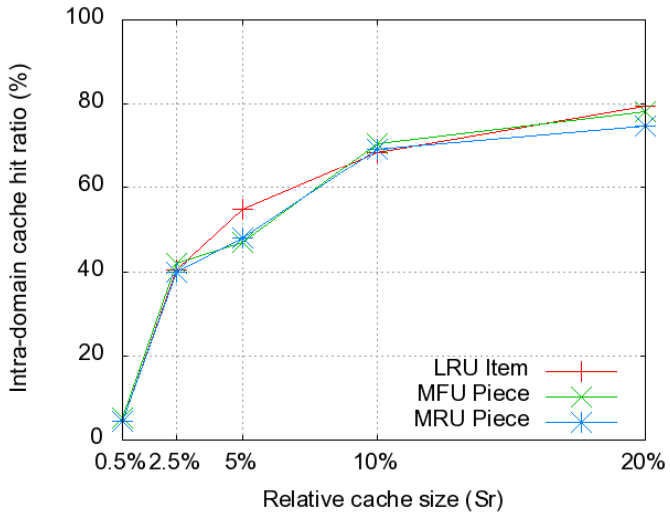
    I.e., minimum cache size to avoid replacements [1]
- Deployment density, $d \in (0,1)$
  - Fraction of access routers enhanced with overlay functionality
- Localizability of traffic
  - Highly depends on item popularity inside a domain
    - High popularity favors cache availability
  - Localizability factor, $l \in (0,1)$
    - $l = 0$, all nodes uniformly dispersed throughout the AS's
    - $l = 1$, all nodes inside a single AS

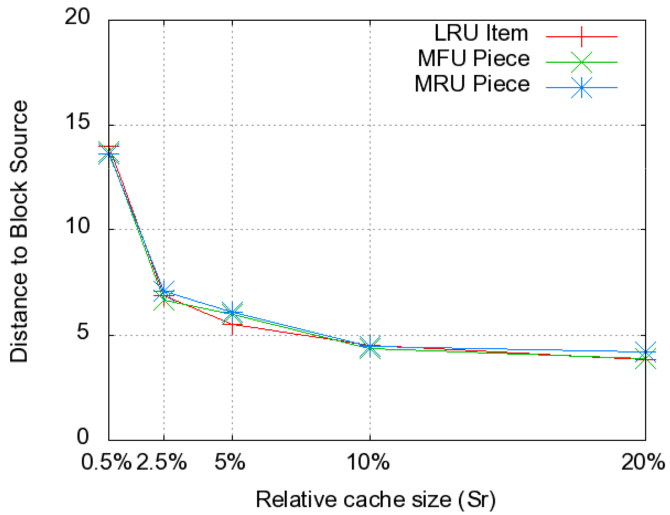
[1] L. Fan, P. Cao, J. Almeida, and A. Z. Broder, "Summary cache: a scalable wide-area web cache sharing protocol," *IEEE/ACM Transactions on Networking,* vol. 8, no. 3, pp. 281-293, 2000.

Results: cache replacement policies

l = 0, d = 0.25, 8 MB Piece, LRU vs. MFU–Intra vs. MRU–Intra



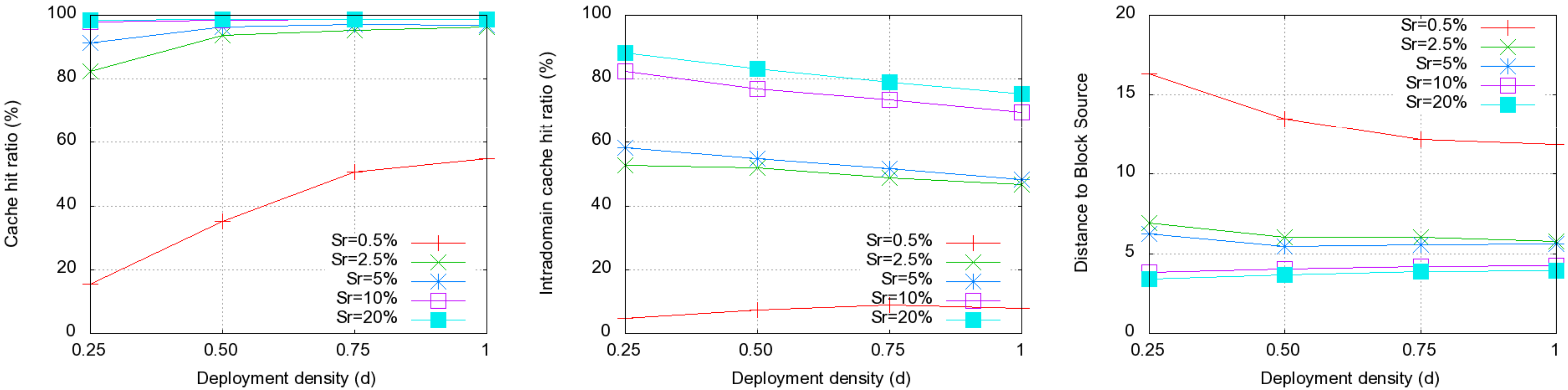




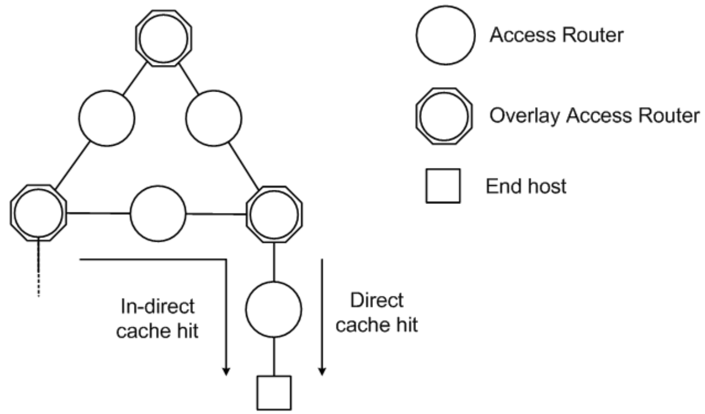
- No significant difference between policies
  - Same performance with simpler, file-oblivious MFU/MRU-Intra policies
- High cache hit ratios
  - Taking advantage of cache multiplicity
  - Overlay multicast minimized
- Localizing traffic
  - High CHR–Intra values for $S_r \geq 2.5\%$
  - Reduced travelled distances

Results: incremental deployment

l = 0.5, 8 MB Piece, MFU-Intra



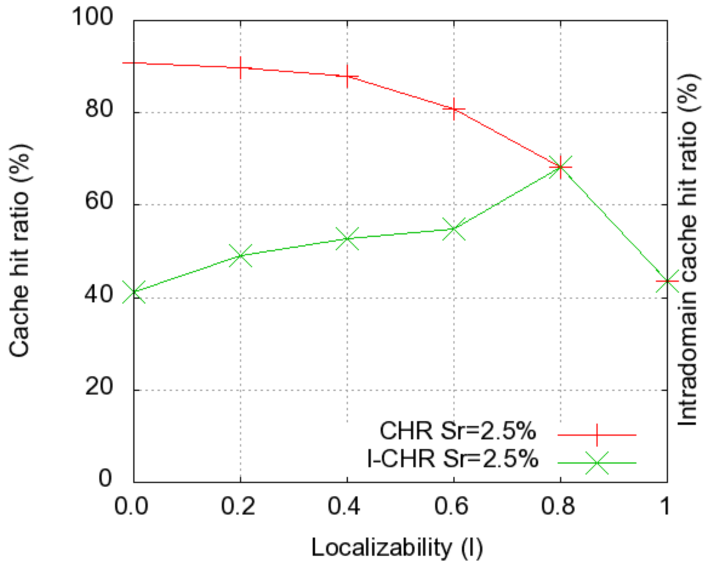
- Higher CHR for denser deployments
  - Taking advantage of the increased caching space in the entire network
- CHR-Intra decreases with deployment density
  - Increased overlay size, increased overlay (stretched) routing
  - Less *direct cache hits*
  - Increasing interdomain cache provision
- Slight reduction of travelled distances
  - More caching locations, decreased distances
  - Less direct hits
- Sparse deployments yield good performance!
  - Low investment cost



Results: Localizability

d = 0.25, 8 MB Piece, MFU-Intra

- Higher localizability imposes greater stress on caches
  - Reducing CHR
  - Multicast gradually takes over
- Taking advantage of localized request patterns
  - Increasing CHR-Intra
  - Up to the cache size limit



Conclusions & Future Work

- Resource sharing enabled by information awareness
- Overlay character facilitating deployment
- Exchanging traffic with storage
  - Building on cache multiplicity
- Avoiding (stretched) overlay multicast as possible
  - Building though on its forwarding scalability
- Sparse deployments enough to rip the benefits
  - Low investment cost
- Next Steps:
  - End user experience
    - Direct comparison with BitTorrent
  - Gaining control of inter-domain cache provision
    - *Canonical* Pastry

Thank you!
Questions?

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