WELCOME

An analytical model of data transfer in content-centric networks

G. Carofiglio

joint work with M. Gallo (Orange labs), L.Muscariello (Orange labs), D.Perino (Bell labs)

Content Centric Networking

Today's Internet

- Ever-growing amount of digital info
- From point-to-point to (multi) point-to-multipoint info dissemination
- Connectivity diversity
- Waste of resources in content replication!

Names not addresses

Packets self-identification

Packets self-certification

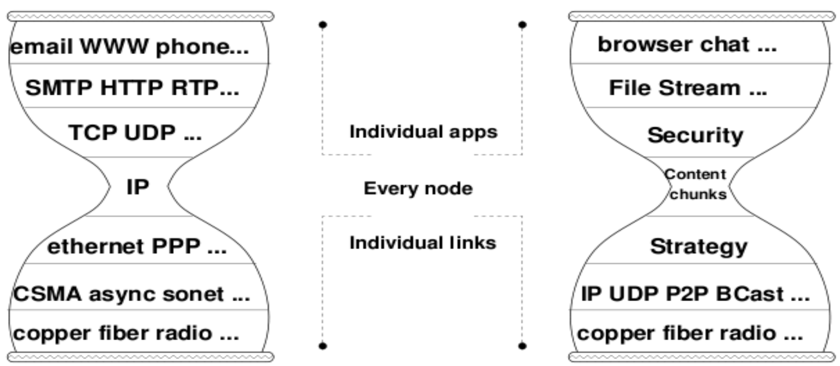
Receiver-based transport

In-network storage

CCN advantages

- Simplified network management
- Traffic localization
- Seamless, ubiquitous connectivity
- Congestion reduction
- Effective Security

Before… …After



Goal

- Performance evaluation of the CCN transport paradigm
  - analytically characterize average throughput/delivery time
  - account for the interplay between receiver-driven transport layer and in-network caching

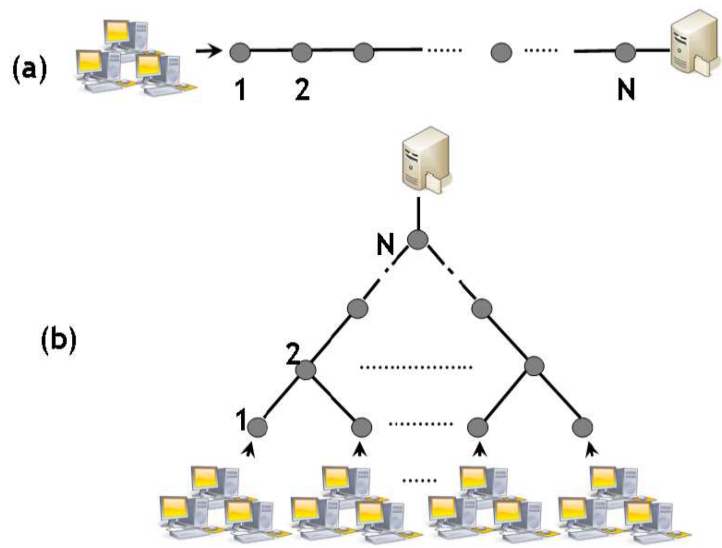
- Explicit data transfer rate formula
  - To develop an analytical tool for the design of a CCN window-based flow control
  - network dimensioning tool

System description

- M different content items organized in K popularity classes, $m=M/K$ in each class
- Content popularity distribution: Zipf

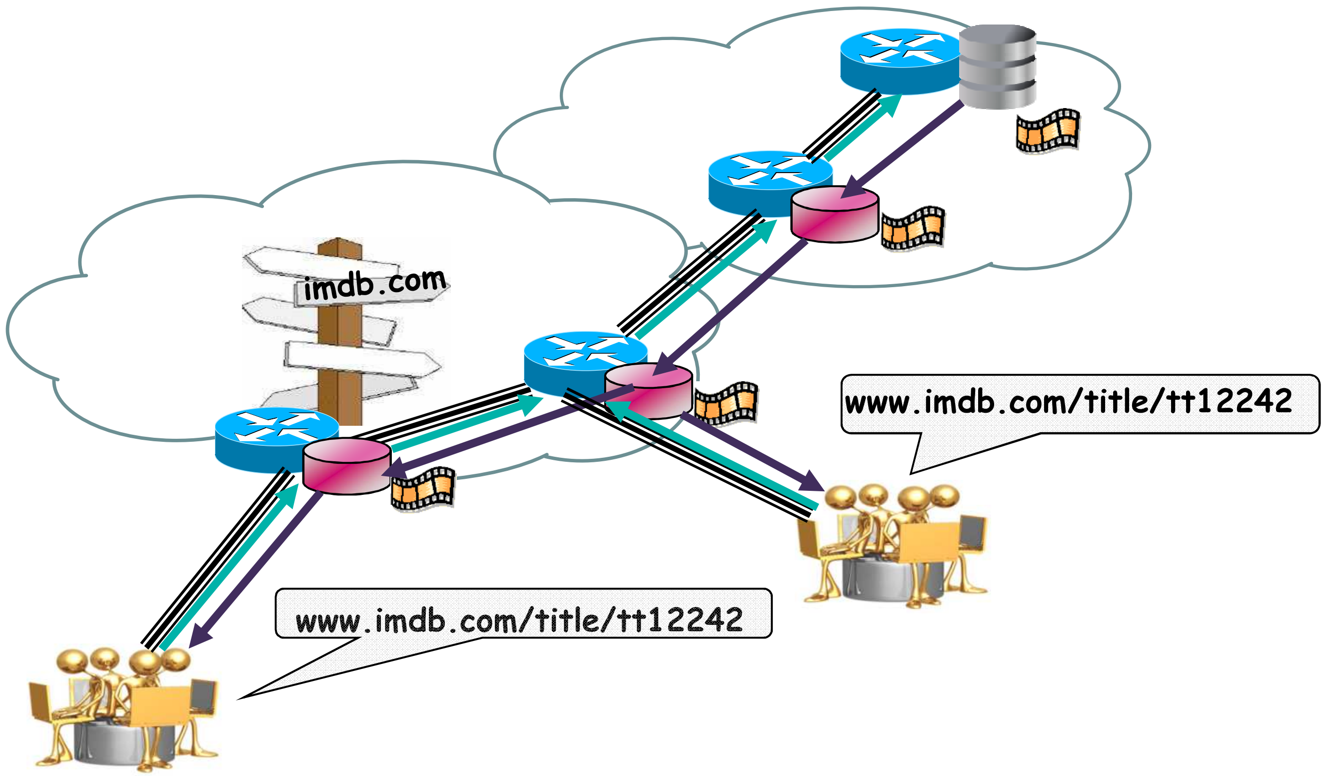
$$q(k) = c/k^{\alpha} \quad k = 1, \ldots, K \quad \alpha > 1$$

- Average content size σ [chunks]
- Content store size x [chunks]
- Shortest path routing
- Link delays
- Topologies
  - (a) linear topology
  - (b) binary tree



- No bandwidth limitations

Transport layer description



- Interest forwarding along shortest path (FIB)
- Data forwarding with in-path caching (Content Store) on symmetric routes
- Request aggregation on a pending interest (PIT)

Virtual round trip time

Miss probability for class k at node i

$$\mathrm{VRTT}_k = \sum_{i=1}^{N} R_i (1 - p_k(i)) \prod_{j=1}^{i-1} p_k(j)$$

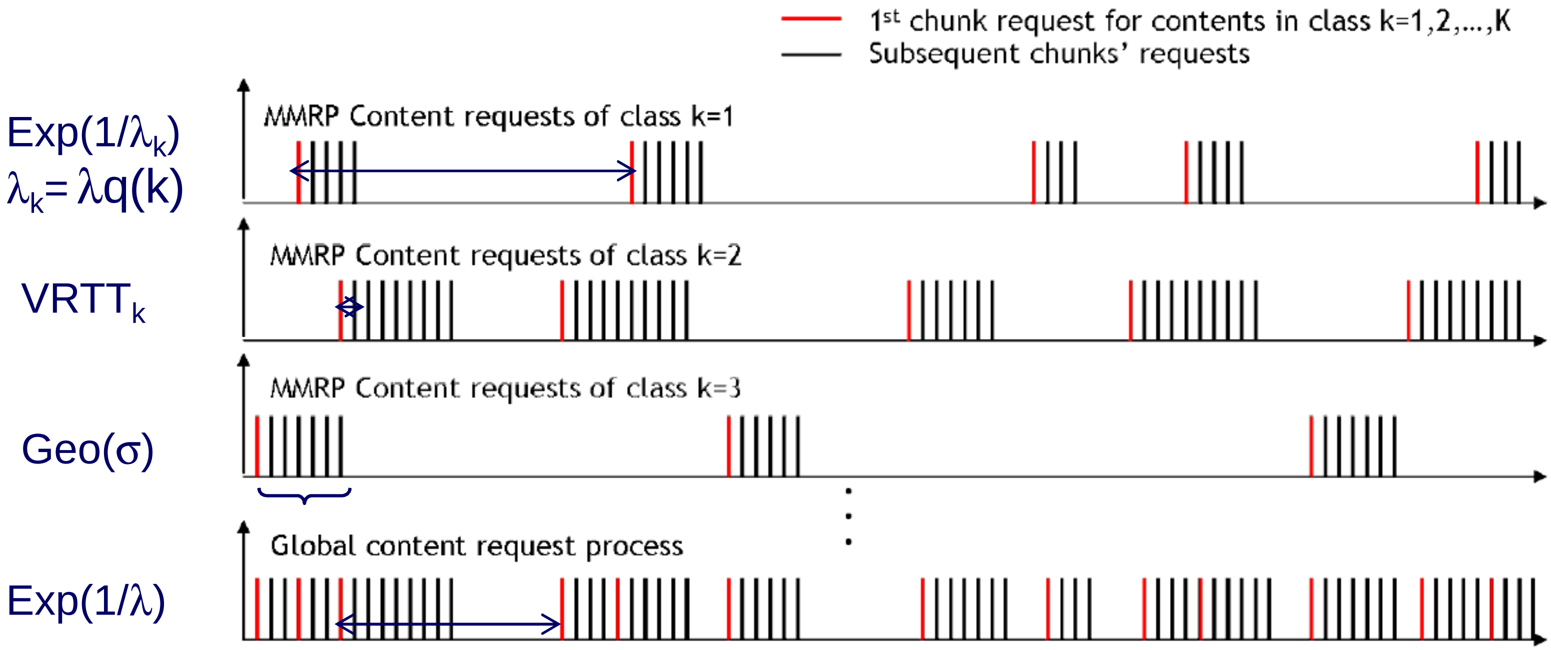
Round trip delay at node i

VRTT represents the average time that elapses between the expression of an interest and data delivery

Similarly to RTT for TCP, VRTT is the average distance in time between the user and the requested data

Request Process

- Two level request process modeled through a Markov Modulated Rate Process (MMRP)



VRTT is assumed to have converged to a stationary value.

Related work

CACHING MODELS

- single LRU cache dynamics (*King 71, Flajolet 92*)
  - miss probability exact formulae (computational expensive)
- combinatorial approaches (*Coffman 99, Starobinski-Tse 01*)
- probabilistic models: *Jelenkovic (92-08)*
  - asymptotics of miss probability for large caches
  - closed-form characterization under Poisson content request arrival process
  - approximation of miss process
- *Kurose-Towsley 09* extends single cache model in *Dan-Towsley 90* to the network case
  - Numerical approximation

All previous models are at content level, most ignore request correlation.

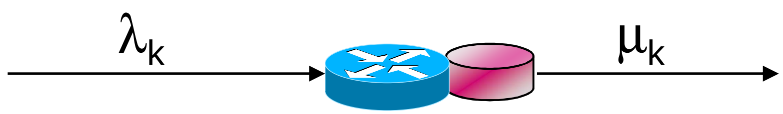
Single cache asymptotics

- Stationary miss probability

$$p_k \equiv p_k(1) = e^{-\frac{\lambda}{m} q(k) g x^{\alpha}}$$

where $1/g = \lambda c \sigma^{\alpha} m^{\alpha-1} \Gamma\left(1 - \frac{1}{\alpha}\right)^{\alpha}$

- Miss rate



$$\mu_k = \lambda_k \exp\left\{-\frac{\lambda}{m} q(k) g(x)^{\alpha}\right\}$$

The output process is a renewal process that we approximate with a MMRP (as in Jelenkovic 08) with intensity μ_k at content level.

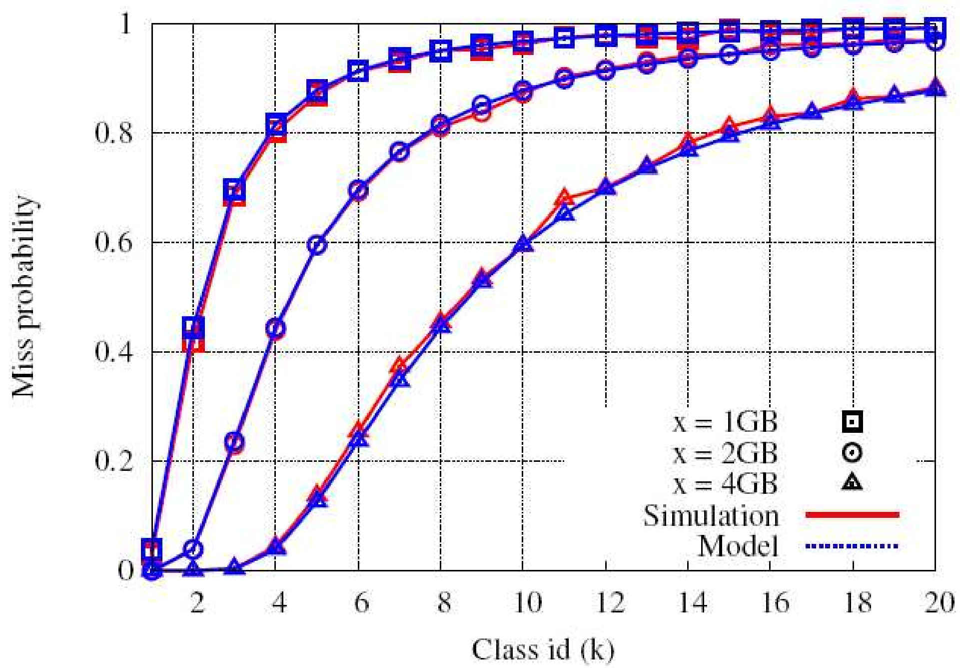
Sketch of the proof

- A request for chunk *i* generates a *miss* at t_n when more than x different chunks are requested after its previous request at t_{n-1}

- Thanks to the memory-less property of the Poisson process (*content level*) and of the geometric size distribution (*chunk level*), the # of different chunk requests in (t_{n-1}, t_n) is independent from that in (t_{n-2}, t_{n-1}), (where $\{t_n\}$ is the miss sequence for class *k*).

- The distribution of the # of requests in between two consecutive requests for the same chunk can be computed from that of the # of requests among two subsequent requests for any two chunks of class k.

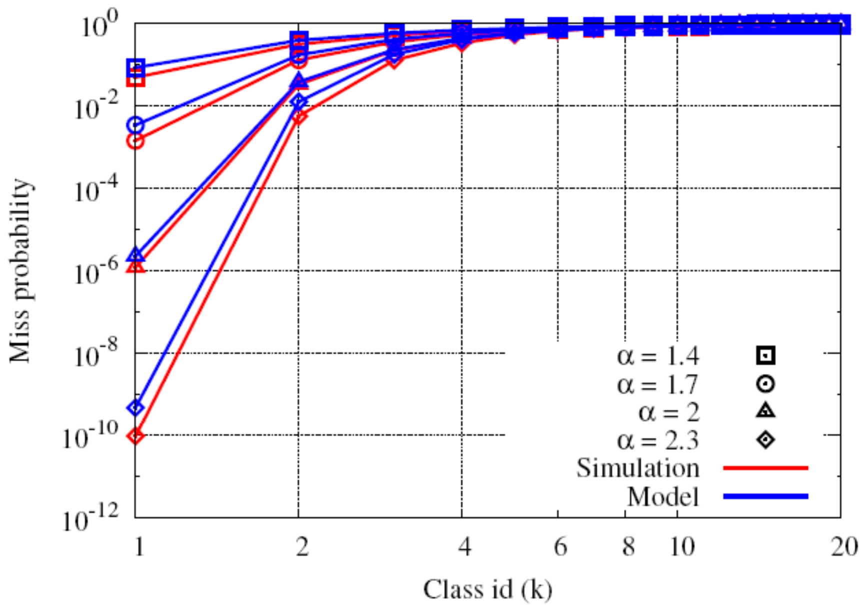
Model/Simulation comparison: miss probability

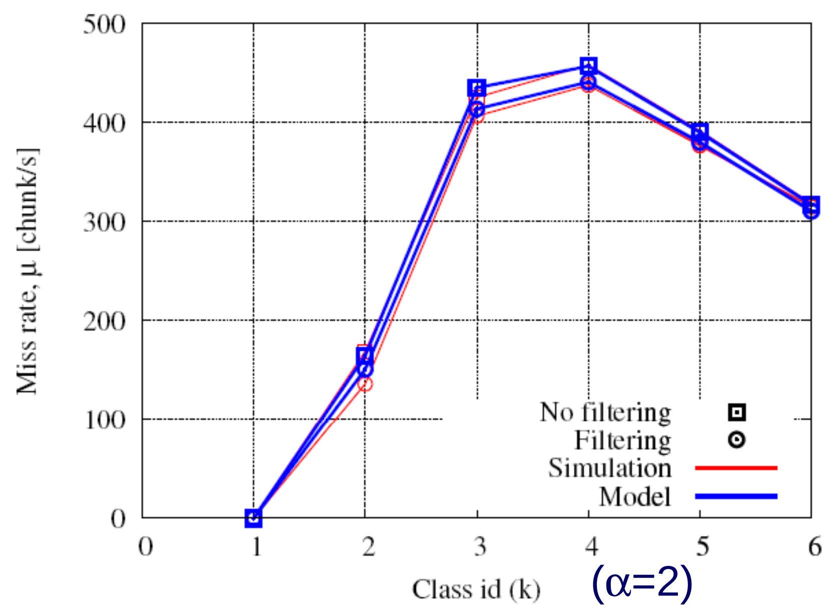


We developed an ad hoc C++ event-driven simulator at chunk level

Parameters: M= 20000, K=400, m=50, α=2, chunk size= 10KB, σ=690 chunks (6.9MB), x=100k÷400k chunks (1GB÷4GB), λ=40 content/s, W=1, no filtering.

Miss probability/Miss rates





Parameters: M= 20000, K=400, m=50, α=(1, 2.5), chunk size= 10KB, σ=690 chunks (6.9MB), x=200000 (2GB), λ=40 content/s, W=1, no filtering.

Simulated time = 7 hours.

Network of caches: binary tree

- For a binary tree topology and in absence of request filtering,

$$\log p_k(i) = \prod_{l=1}^{i-1} \left(\frac{x_{l+1}}{x_l}\right)^{\alpha} p_k(l) \log p_k(1)$$

where $p_k(i)=f(q_k(i))$, and

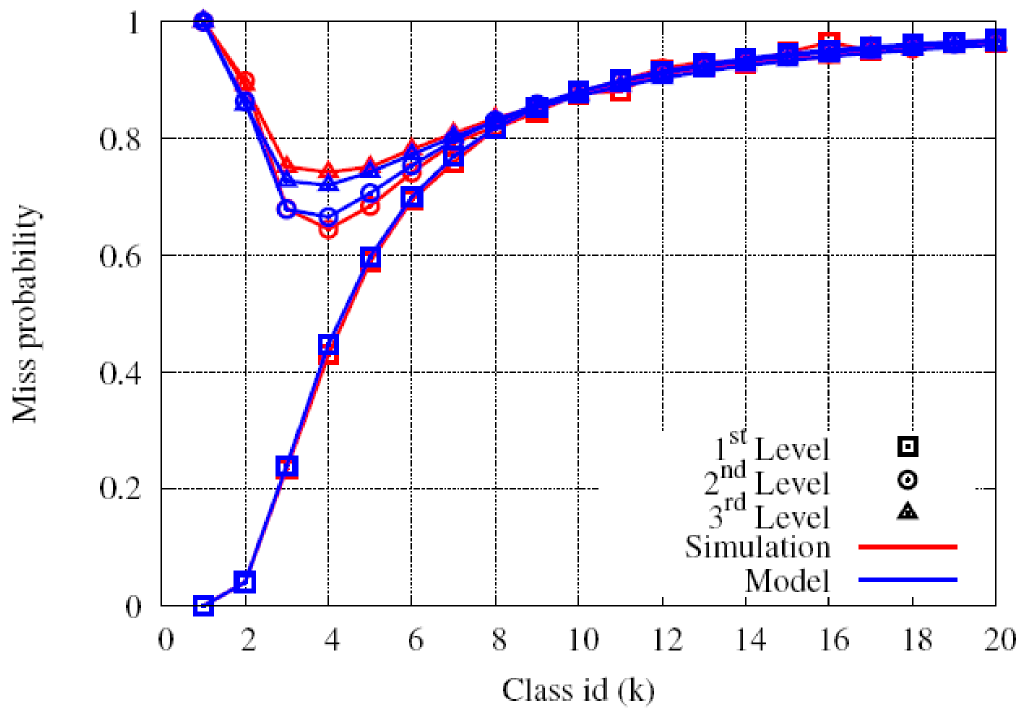
$$q_k(i) = \prod_{j=1}^{i-1} p_k(j) q_k / \sum_{l=1}^{K} \prod_{j=1}^{i-1} p_l(j) q_l.$$

- The miss rate at node i is

$$\mu_k^f(i) = \begin{cases} \lambda_k p_k(1)(1 - p_{filt,k}(1)) & \textit{if } i = 1 \\ 2\mu_k^f(i-1) p_k^f(i)(1 - p_{filt,k}(i)) & \textit{if } i > 1 \end{cases}$$

where pfilt,k(1) accounts for the probability to aggregate requests for the same content in the PIT.

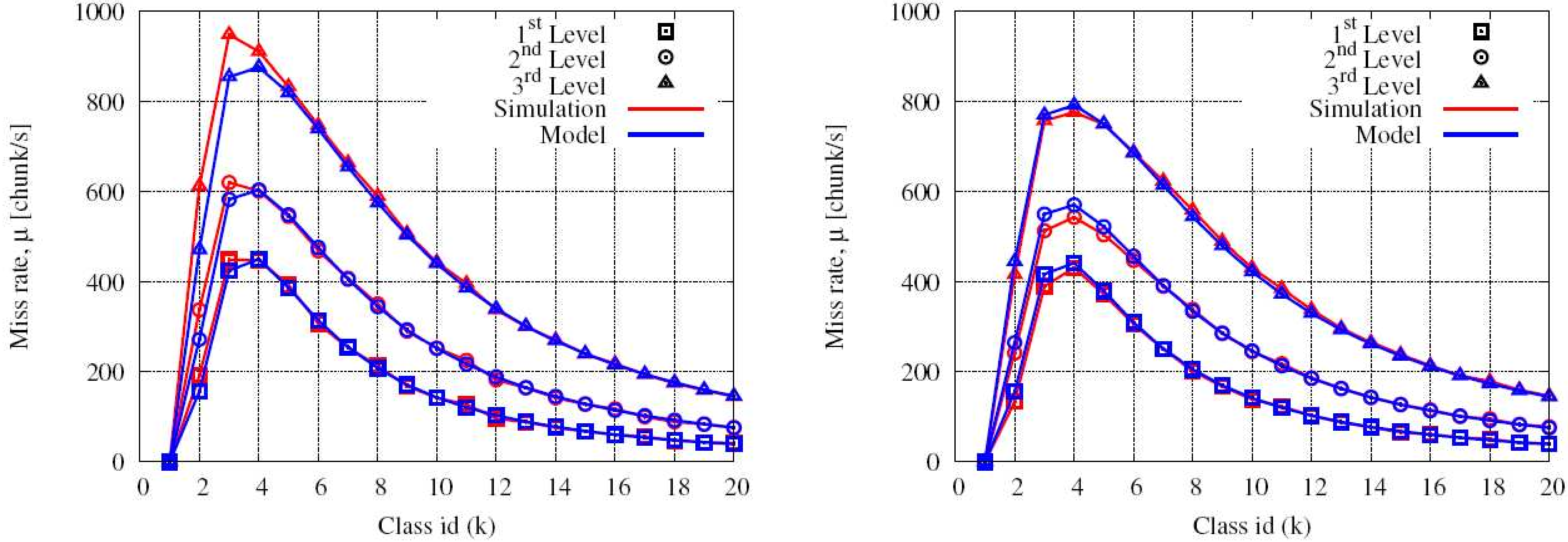
Miss probabilities in the binary tree



Parameters: M= 20000, K=400, m=50, α=0.7, chunk size= 10KB, σ=690 chunks (6.9MB), x=200000 (2GB), λ=40 content/s, W=1, no filtering.

RTT=2ms at each hop.

Miss rates with and without filtering



(a) (b)

Request rate reduction up to 20% at 3rd node with filtering.

Average throughput

- The miss probabilities contribute to the definition of the VRTT for contents in class k. The average throughput in steady state is

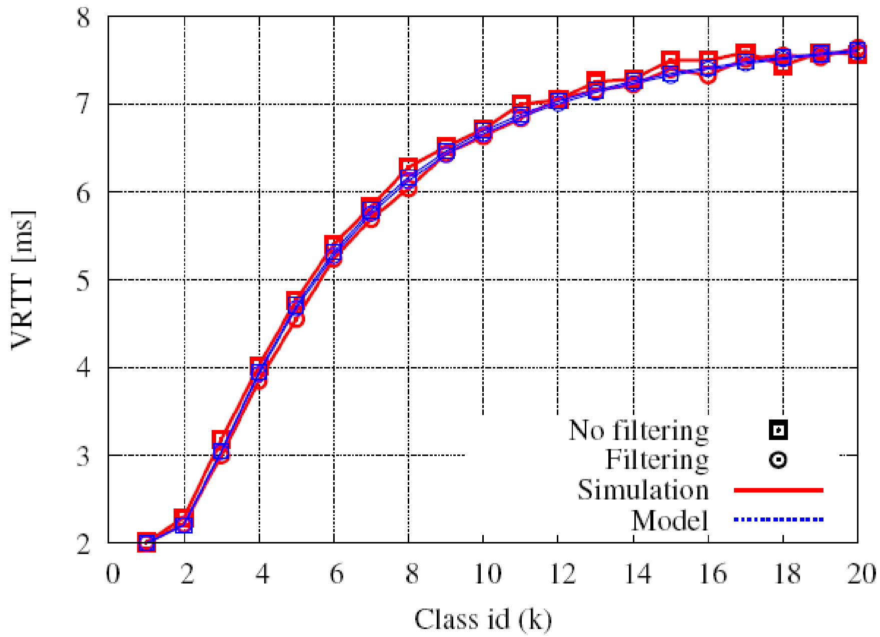
$$X_k = \frac{W}{\mathrm{VRTT}_k}$$

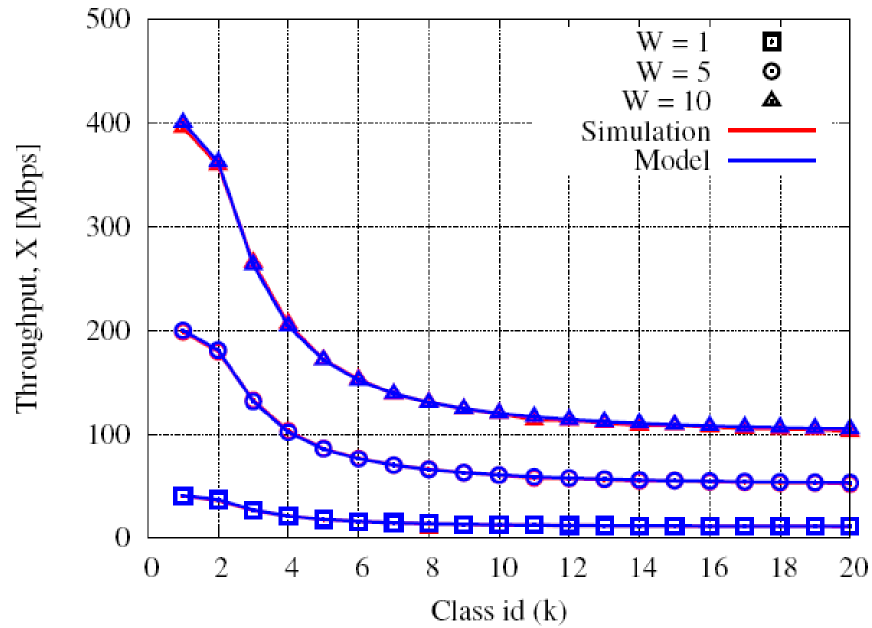
- Letting W vary over time we can define a control over the interest rate such to achieve a target average throughput

- Average delivery time: $T_k = \sigma / X_k$

- The throughput formula is a powerful tool for cache sizing under throughput or delivery time guarantees.

VRTT and Throughput



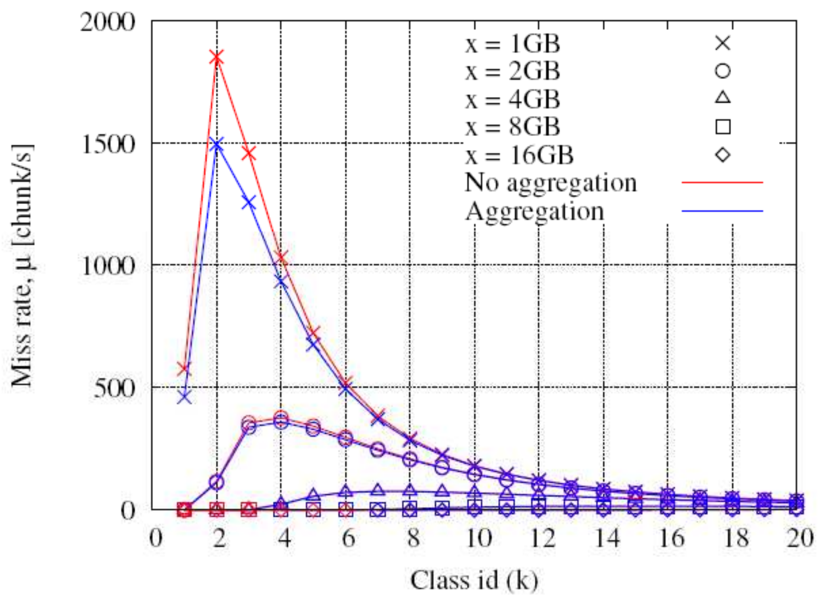


The filtering does not have a large impact of VRTT/throughput values, but it helps reduce overall request traffic.

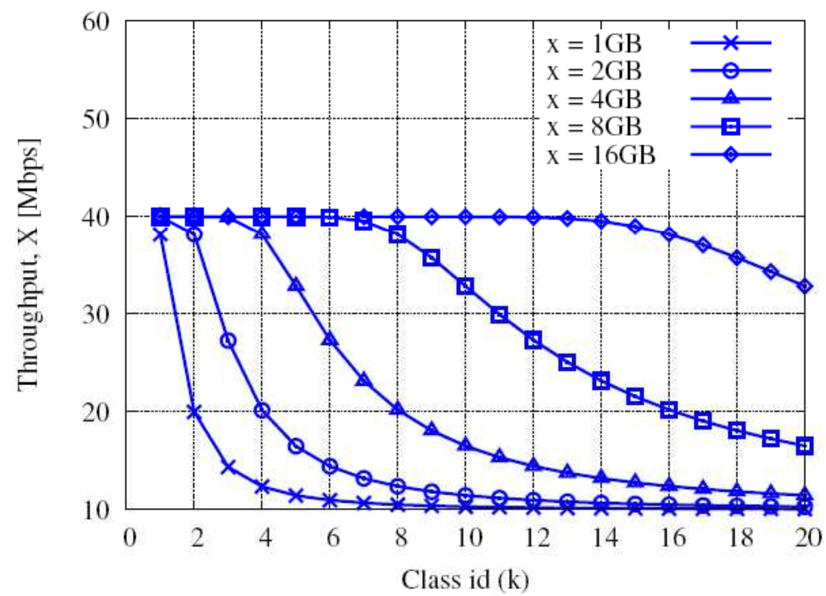
Throughput gain due to parallel downloading is more important for most popular classes due to a smaller VRTT

Dimensioning and Trade-offs

- The model can be used as a tool to
  - quantify network cost to guarantee a certain performance or
  - predict end user performance under a given per-service resource allocation.



Traffic/Storage capacity trade-off



Performance/Network cost trade-off

Parameters: Binary tree, same parameters as before except α=2.3 (YouTube, Daily Motion)

Future directions

We developed an analytical model for the performance evaluation of content transfer in CCN that allows an explicit characterization of steady state dynamics (stationary throughput, content delivery time)

- Model extended to account for limited bandwidth

«Bandwidth and Storage Sharing in Information-Centric Networks », G.Carofiglio, M.Gallo, L.Muscariello, in Proc. of ACM ICN Sigcomm 2011.

- Multi-path case
- Design of a transport protocol with a receiver-based rate control and hop-by-hop congestion control
- Analysis of different cache replacement policies

Questions

More info at **www.anr-connect.org**

www.alcatel-lucent.com