MODELLING THE IMPACT OF CACHING AND POPULARITY ON ADAPTIVE MULTIMEDIA STREAMING IN INFORMATION-CENTRIC NETWORKS

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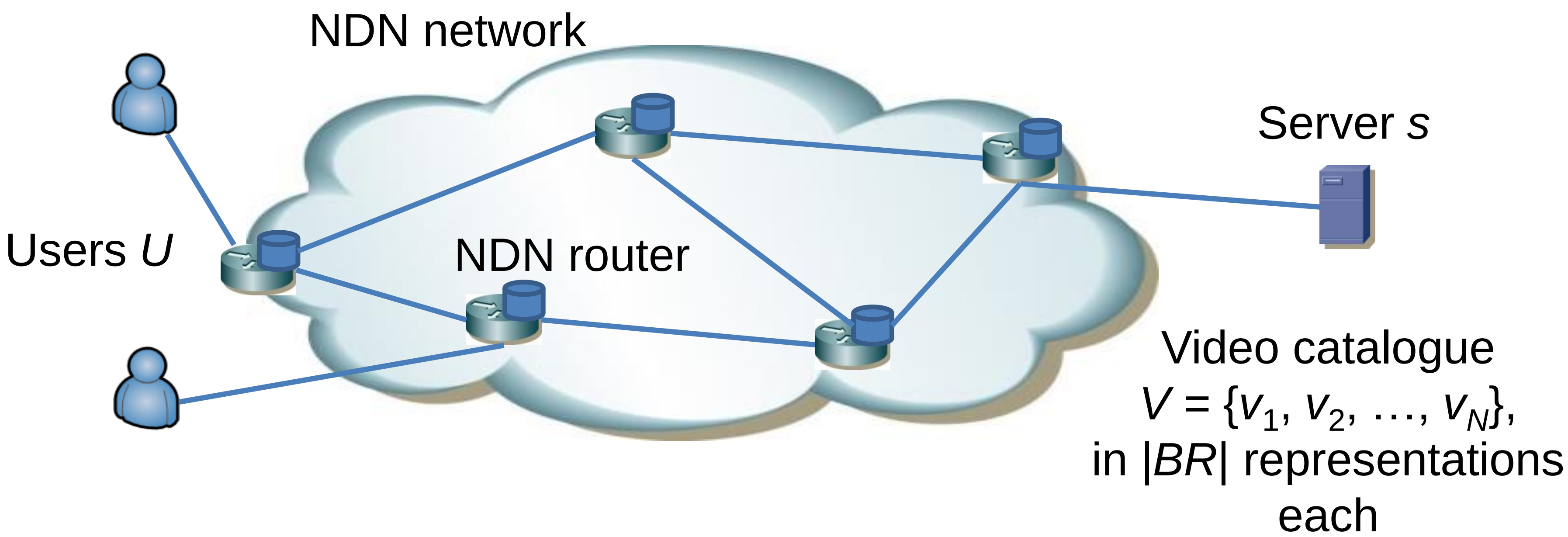
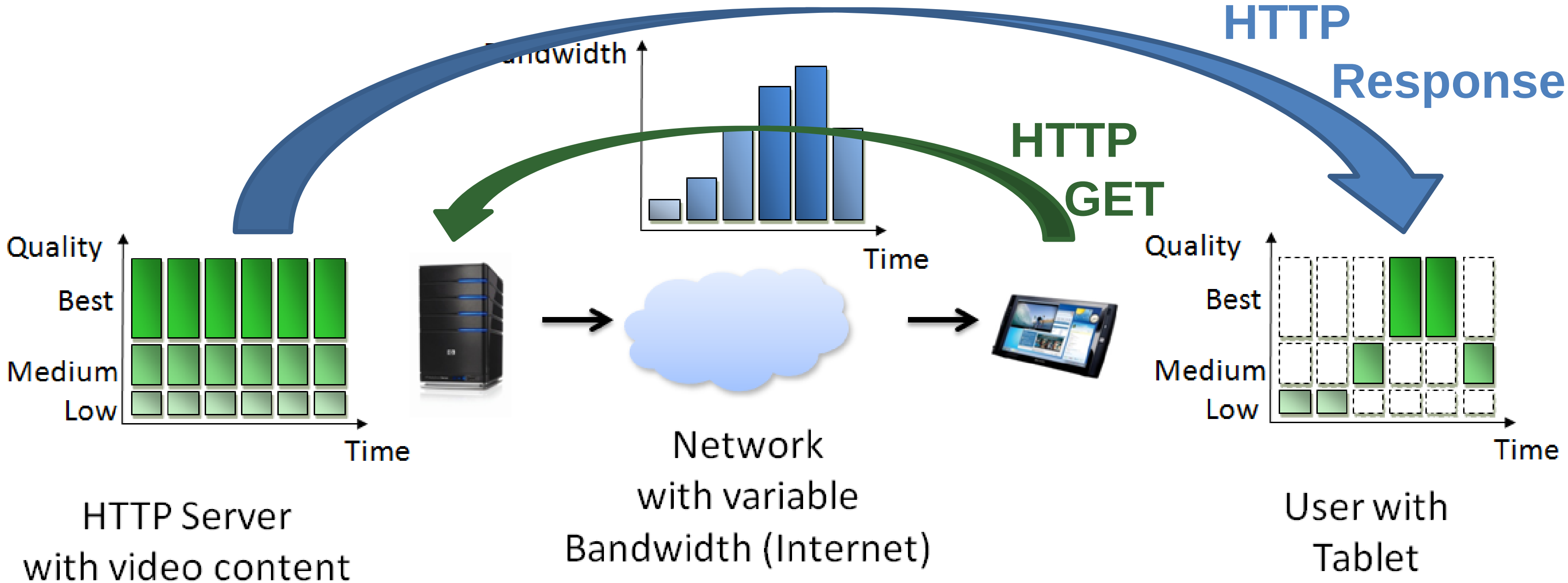
SYSTEM MODEL



Users perform **"Dynamic Adaptive Streaming over NDN"** in a DASH-like manner

(MPEG-)DASH IN A NUTSHELL

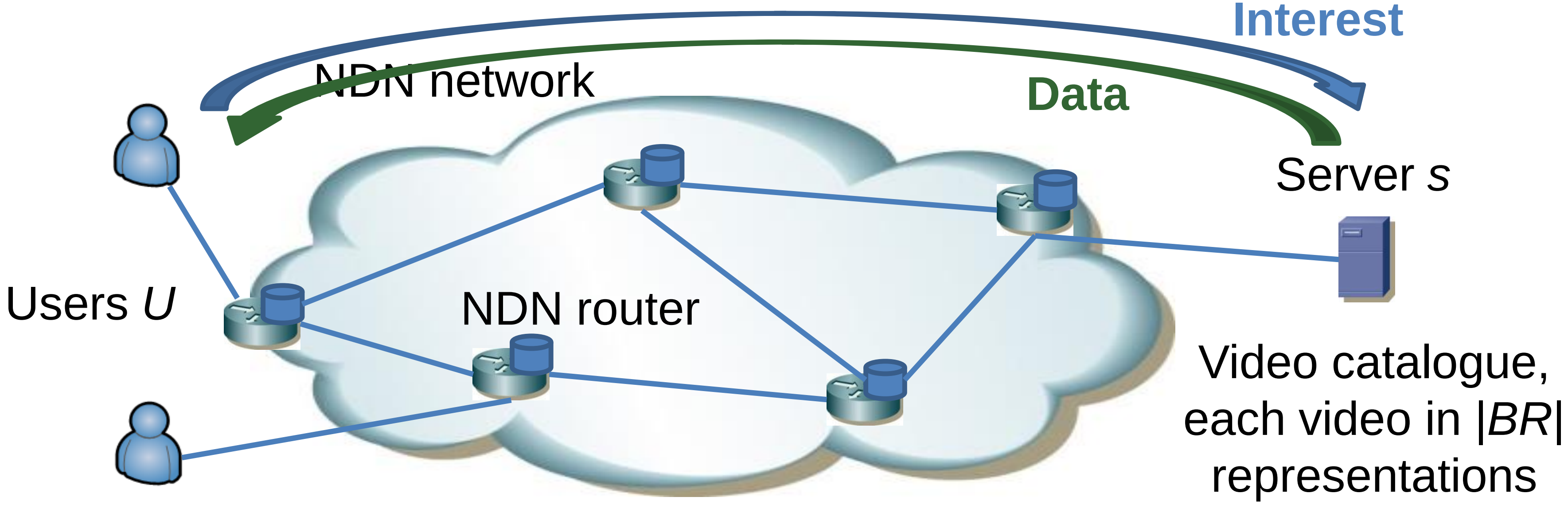
- **DASH := Dynamic Adaptive Streaming over HTTP** (http://dash.itec.aau.at)
- Goal: efficient, adaptive multimedia streaming over HTTP/TCP in today‘s Internet



MULTIMEDIA STREAMING IN NDN – OUR APPROACH

Combine **MPEG-DASH & NDN**

I.e., integrate **DASH-style content provisioning and delivery into NDN** architecture → **“DAS over NDN“**



PROBLEM

Determine (model for)

- **fair bandwidth allocation**

for dynamic adaptive streaming in NDN, while

- **considering (maximizing) content quality** (users‘ satisfaction)

and understanding the impact of

- **in-network caching** and
- **content popularity**,

to get an upper bound for achievable quality

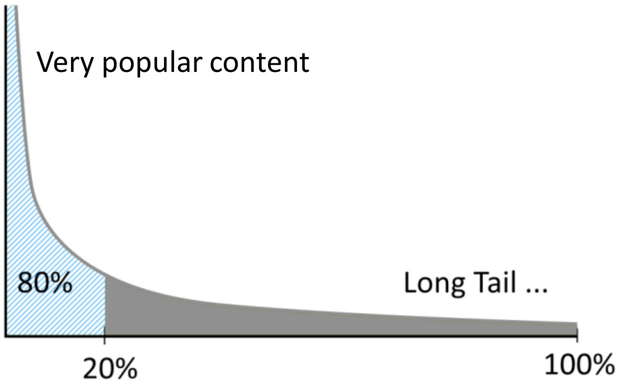
CONTENT POPULARITY

- **Usual model: Zipf‘s Law (Power Law)**

$\mathcal{V}$ ... Set of videos

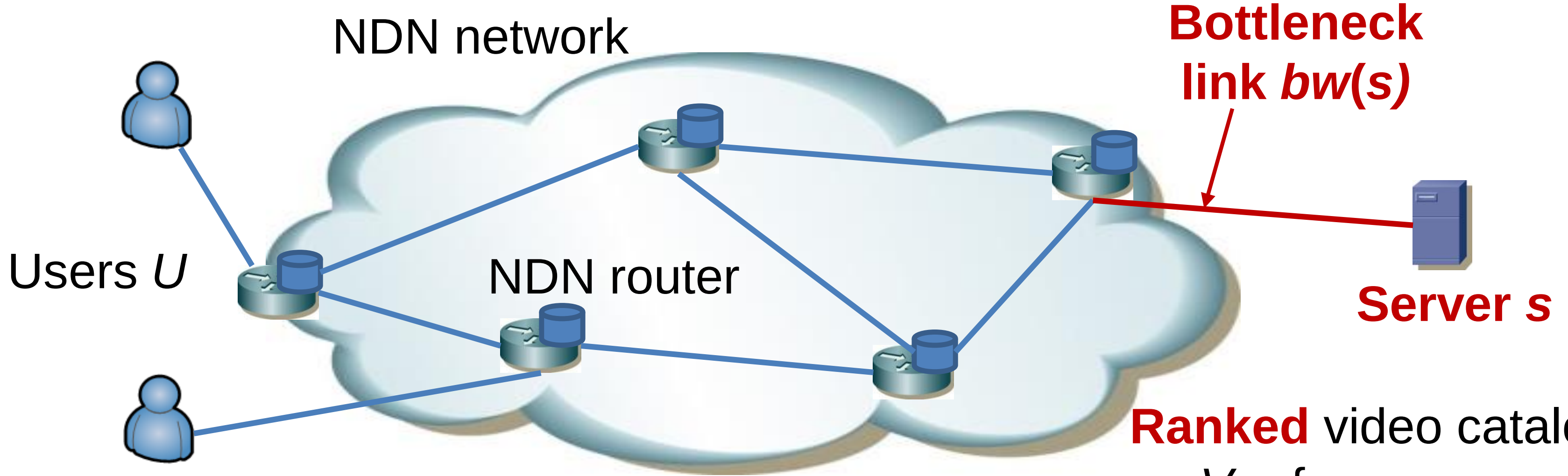
$$\mathcal{V} = \{v_1, v_2, \ldots, v_N\}$$

$$\mathrm{Pop}(v_i) = \frac{1}{i^\alpha} \Big/ \sum_{k=1}^{|\mathcal{V}|} \frac{1}{k^\alpha}$$



- Typical values for **α** in multimedia context:
  - 0.0 (Uniform), **0.8, 1.2,** 2.0 (Very popular)

PROBLEM SETTING I



Ranked video catalogue
$V = \{v_1, v_2, \ldots, v_N\}$,
in $|BR|$ representations and
with different popularity each

APPROACH

“Traffic Shaping“ & Dyn. Adaptive Streaming:

- **On the server, shape traffic,** i.e., control the bitrate of each stream, such that all streams share the available capacity **in a fair way** (e.g., quality aware)
- **Minimize unused bandwidth**
- **Popularity** considered via ranked content catalogue
- Various approaches (for DASH) exist, e.g., Begen et al., NOSSDAV 2013

EXAMPLE

- Bottleneck link capacity: *bw*(*s*) = 10 Mbit/s
- Video bitrates: 1, 2, 5 Mbit/s
- **Share capacity** for 2, …, 6 users and **minimize unused bandwidth**

Cap.	#User	User 1	User 2	User 3	User 4	User 5	User 6	Unused
10	2	5	5					**0**
10	3	5	2	2				**1**
10	4	5	2	2	1			**0**
10	5	2	2	2	2	2		**0**
10	6	2	2	2	2	1	1	**0**

Determine Average Quality without Caching

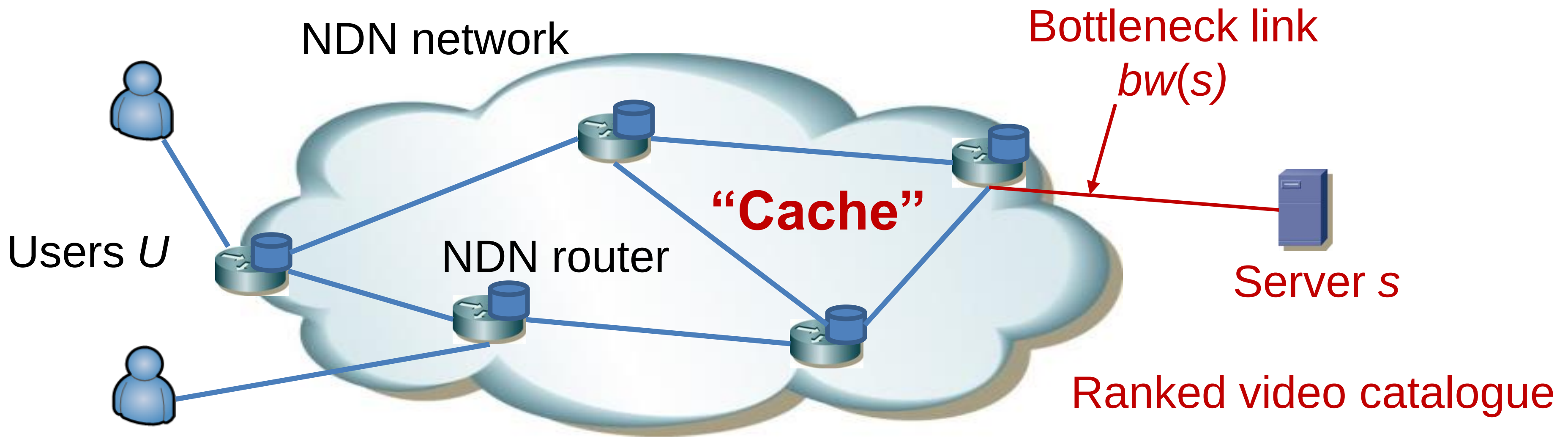
$\pi(u_i) \leftarrow 0,\ \forall i \in \{1, 2, \dots, |\mathcal{U}|\}$: ▷ Initialize policy
$b_{last} \leftarrow 0\,;\ \gamma_{last} \leftarrow 0$ ▷ Helper variables
$c \leftarrow bw(s)$ ▷ Remaining capacity
$\mathcal{BR}' \leftarrow \{b \in \mathcal{BR} : b \geq b_{feasible}\}$
for all $b \in Sorted(\mathcal{BR}')$ **do** ▷ Iterate over sorted bitrates
  if $c < b$ **then**
    break ▷ Not enough capacity remaining
  end if
  $\gamma_b = \min\left\{|\mathcal{U}|, \left\lfloor \frac{c}{b - b_{last}} \right\rfloor\right\}$ ▷ Satisfy
  $c \leftarrow c + \gamma_b \cdot (b_{last} - b)$ pacity
  $\pi(u_i) \leftarrow b,\ \forall i \in \{1, 2, \dots, \gamma_b\}$ policy
  $b_{last} \leftarrow b\,;\ \gamma_{last} \leftarrow \gamma_b$
end for

Simple and fast algorithm, but does not take caching into account!

Algorithm 1: Determine a bandwidth allocation which prefers users consuming popular content, and maximizes the quality for all users.

PROBLEM SETTING II

Introducing caching as an **"ideal NDN cache"**:



Question: How much can we gain (theoretically) in terms of quality by having k items available in an "ideal cache"?

NOTATIONS AND SETTINGS

$bw(s) \in \mathbb{N}$	Server capacity in Kilobit/s	**100, …, 1500 Mbit/s**
$\mathcal{U}$	Set of users	**|*U*| = 1000 users**
$\mathcal{V}$	Set of videos	**|*V*| = 10 videos**
$\mathcal{BR} \subset \mathbb{N}$	Set of bitrates in Kilobit/s, e.g.: $\mathcal{BR} = \{0, 500, 1000, 1500, \ldots, 9500, 10000\}$	**|*BR*| = 20**
$b_{min} > 0$	Minimum Bitrate, $b_{min} := \min\{b \in \mathcal{BR} : b \neq 0\}$	
$b_{avg} > 0$	Average Bitrate, $b_{avg} := \frac{bw(s)}{\|\mathcal{U}\|}$	
$b_{feasible} \in \mathcal{BR}$	Bitrate such that every user is able to stream $b_{feasible} := \max\{b \in \mathcal{BR} : b \leq b_{avg}\}$	
$\text{SSIM}(v, b) \in [0, 1]$	Structural Similarity of video $v \in \mathcal{V}$ at bitrate $b \in \mathcal{BR}$	
π	Traffic shaping policy	
$\pi(u) \in \mathcal{BR}$	Bitrate in Kilobit/s for user $u \in \mathcal{U}$	
$\pi(v) \in \mathcal{BR}$	Bitrate in Kilobit/s for video $v \in \mathcal{V}$	
$\text{Pop}(v) \in [0, 1]$	Popularity of a video $v \in \mathcal{V}$	

Goal: Determine bitrates

Modeling Caching

Linear Program (Assignment Problem):

$$\Omega = \max \sum_{v \in \mathcal{V}} \mathrm{Pop}(v) \cdot \mathrm{SSIM}(v, \pi(v)) \quad (1)$$

Max. average quality

$$\text{s.t.} \quad \boxed{\sum_{j=1}^{k} \pi(v_j)} + \boxed{|\mathcal{U}| \cdot \sum_{j=k+1}^{|\mathcal{V}|} \mathrm{Pop}(v_j) \cdot \pi(v_j)} \leq bw(s) \quad (2)$$

$$\forall v \in \mathcal{V} : \pi(v) \in \mathcal{BR} \quad (3)$$

Cached videos are only transfered once from the origin server

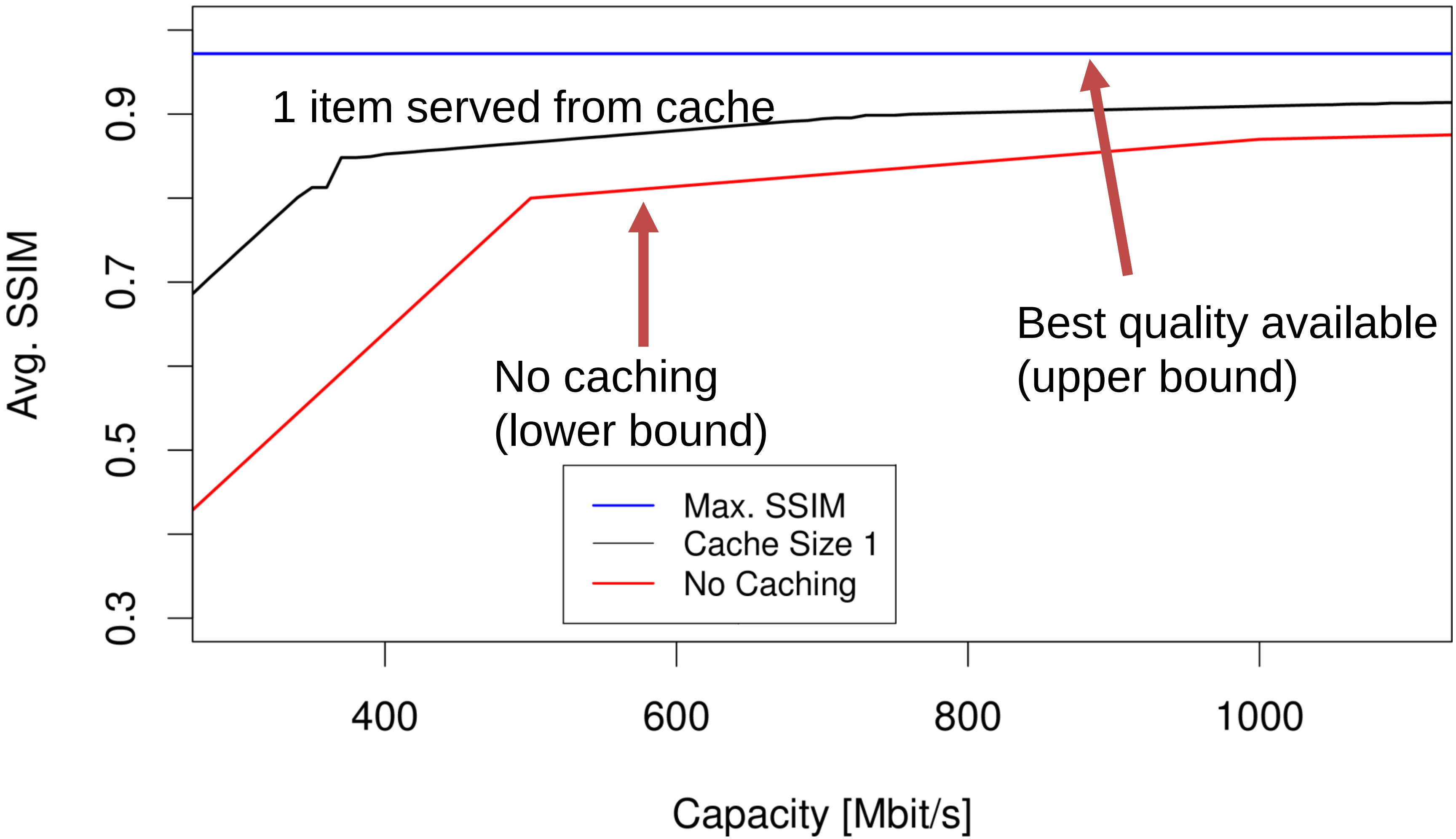
Remaining videos are transfered `Popularity * |U|` times

k … Number of items in cache

ASSUMPTIONS

- **Critical:** clients streaming the same video need to request **the same representation(s)** for caching to be effective
  - Traffic shaping helps to achieve that
  - Extension: cooperative or cache-aware adaptation behavior on clients
- **Alternative: Layered Content (SVC)**
  - Content with higher quality depends on content with lower quality, therefore redundancy is reduced
  - Improves cache usage, as content with lower quality is more likely to be cached already

AVERAGE QUALITY WITH CACHING (K=1)



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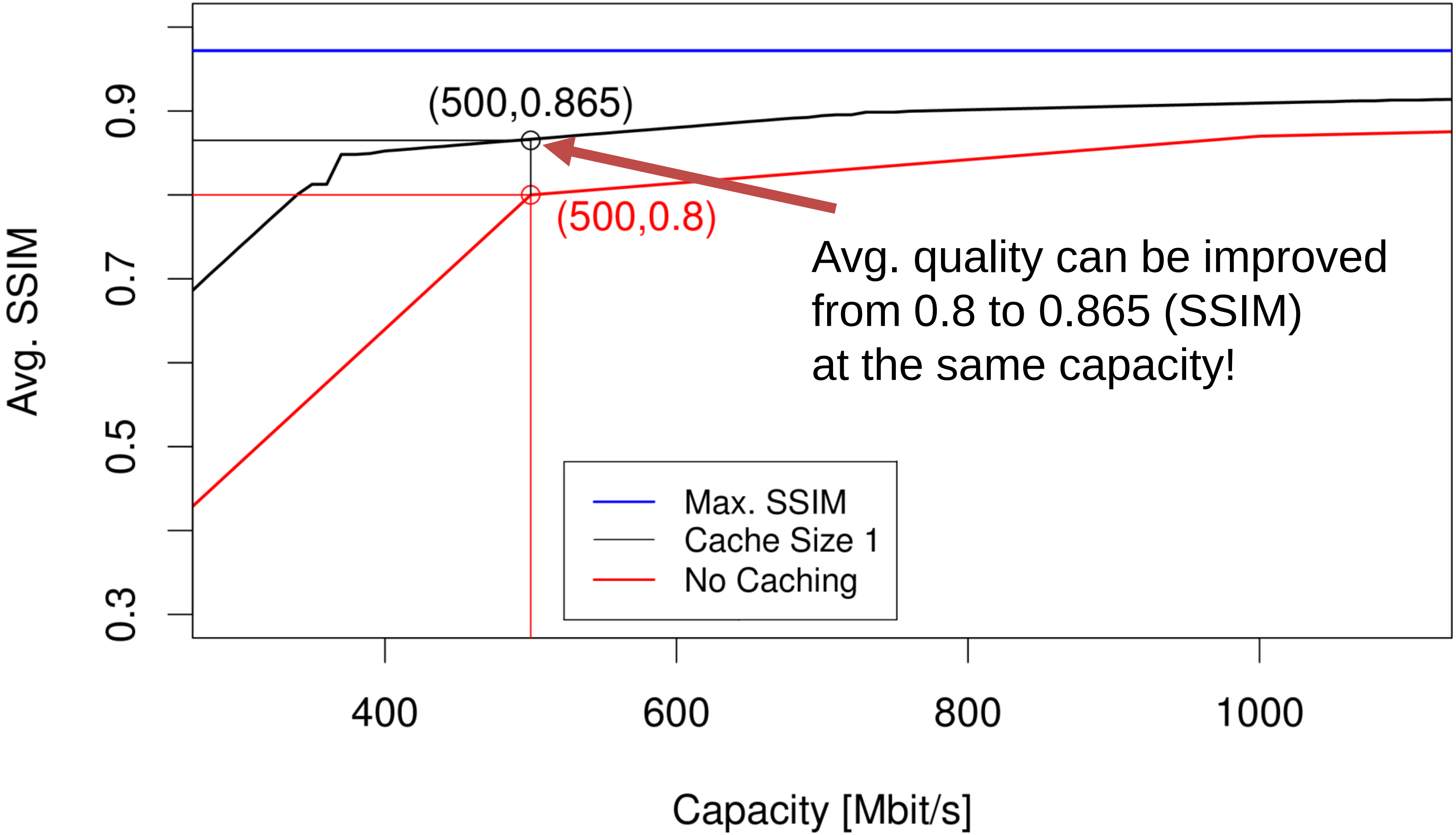
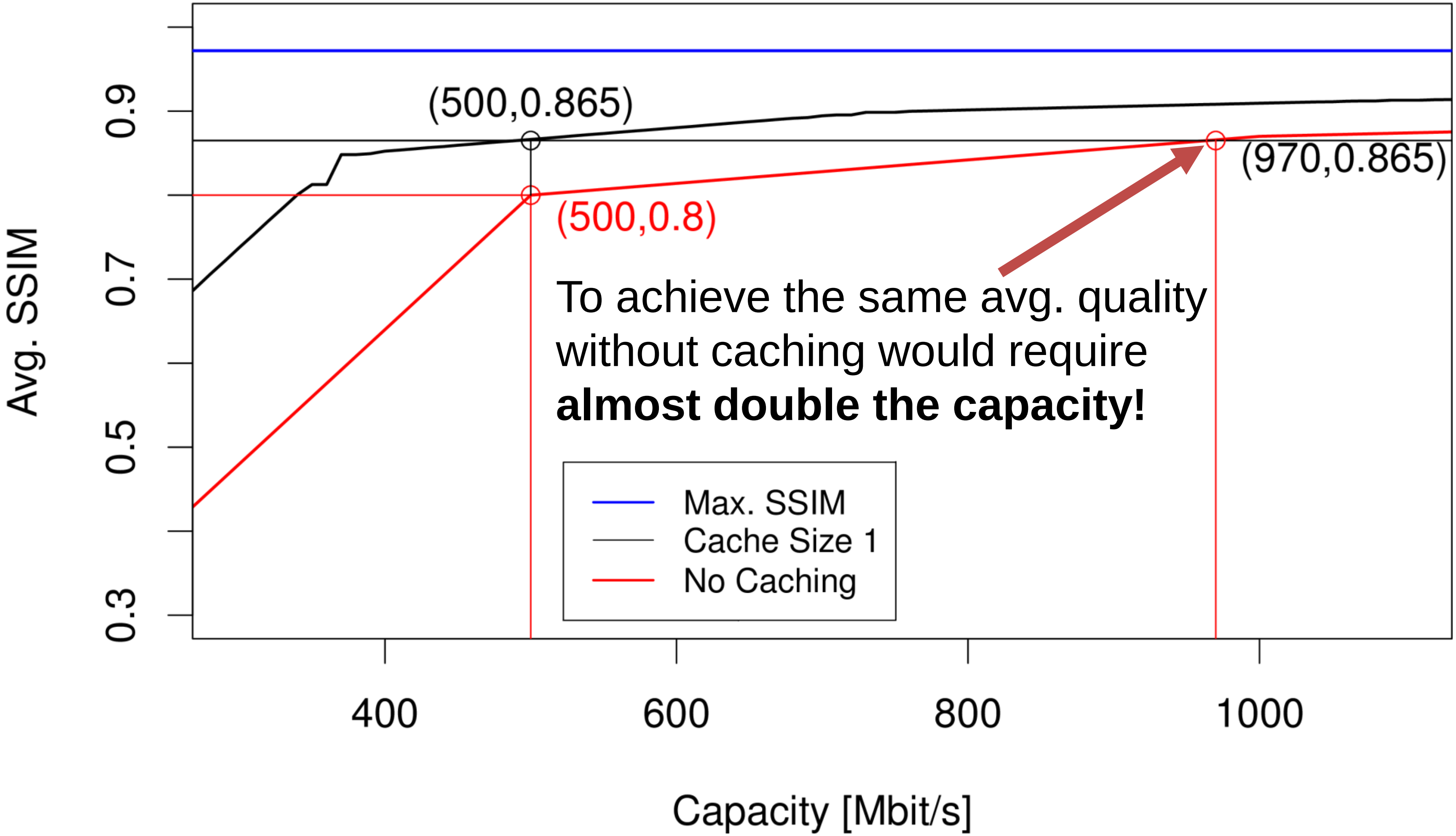
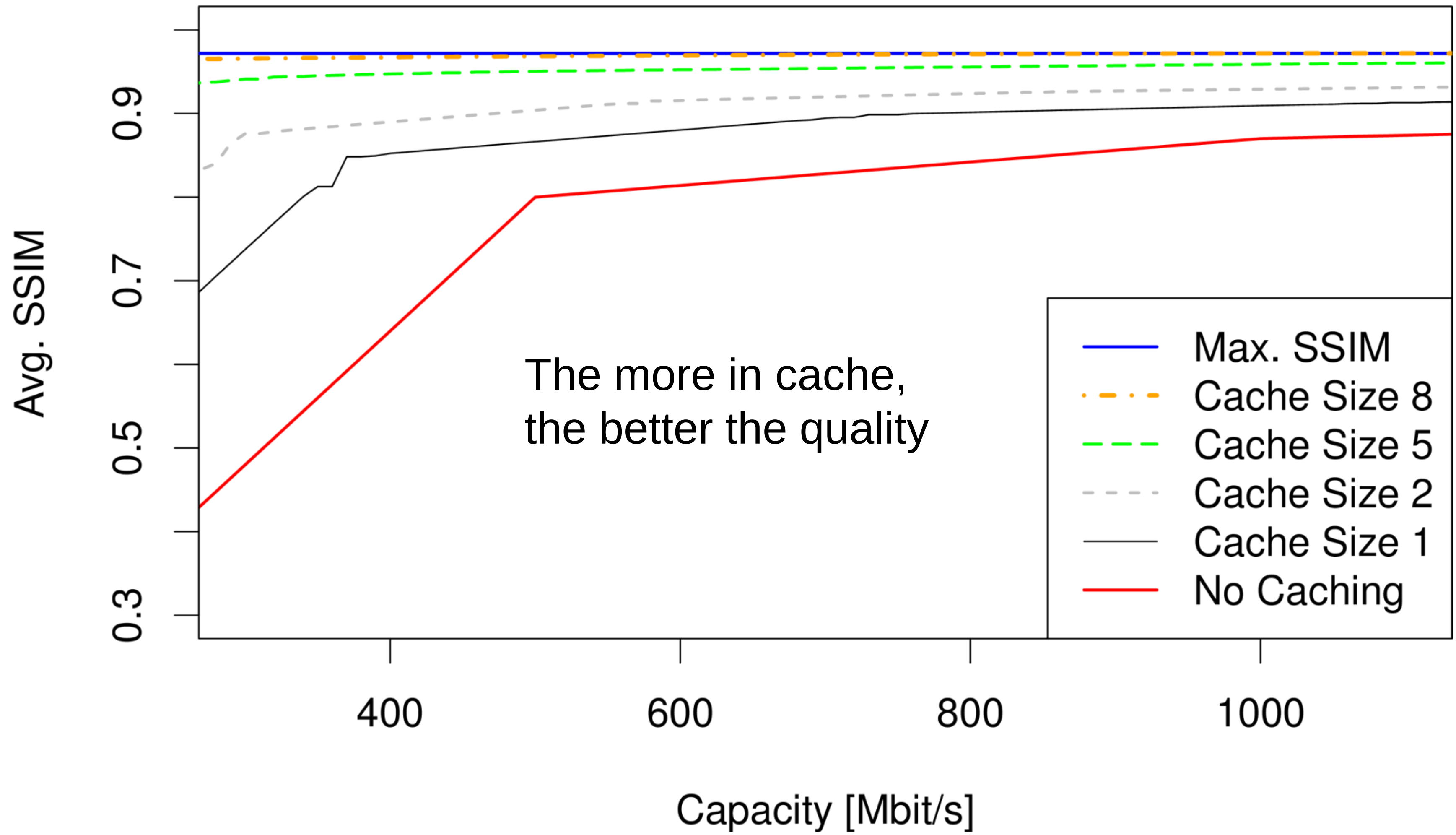


AVERAGE QUALITY WITH CACHING (κ=1)

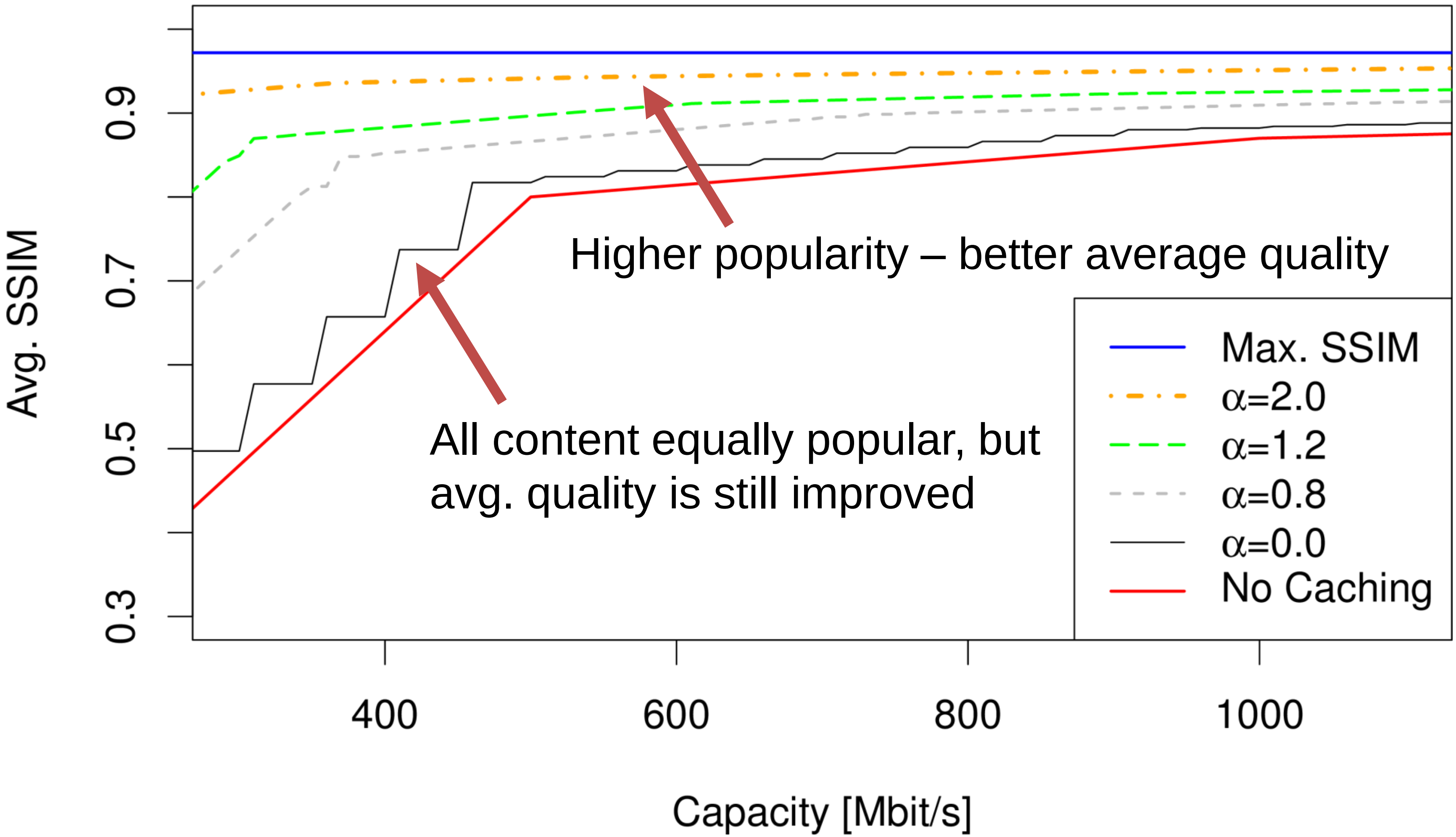


To achieve the same avg. quality without caching would require **almost double the capacity!**

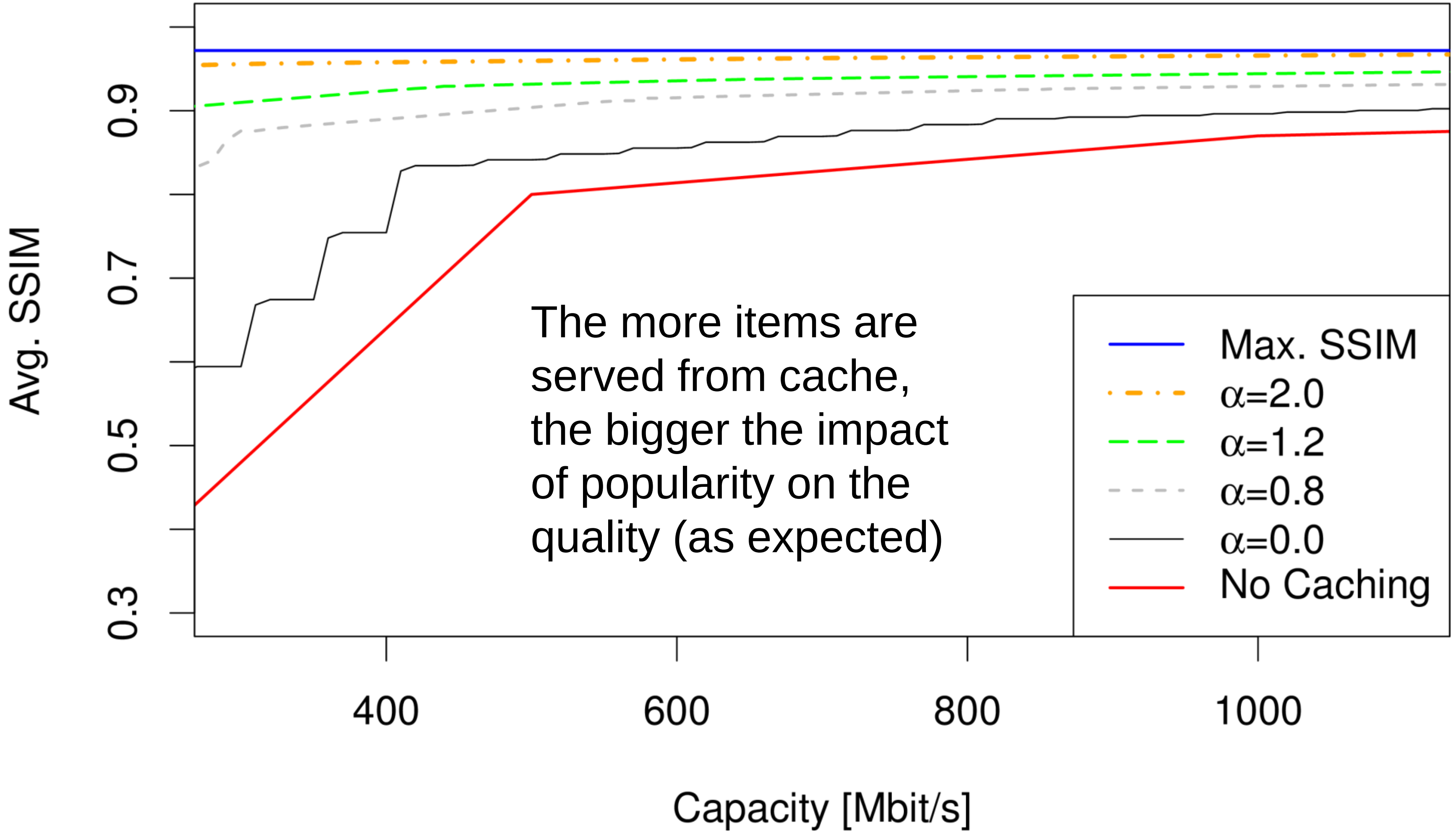
Impact of Cache Size



IMPACT OF POPULARITY (κ=1)



IMPACT OF POPULARITY (K=2)



The more items are served from cache, the bigger the impact of popularity on the quality (as expected)

Conclusion and Results

- We modeled an **upper bound for the impact of popularity and caching** of concurrent adaptive multimedia streams in NDN
- We showed the potential impact of caching *k* items
- Caching always helps, even in the case of a uniformly popular content
- **Critical:** clients streaming the same video need to request **the same representation(s)** for caching to be effective