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Data-driven QoE optimization techniques for multi-user wireless networks

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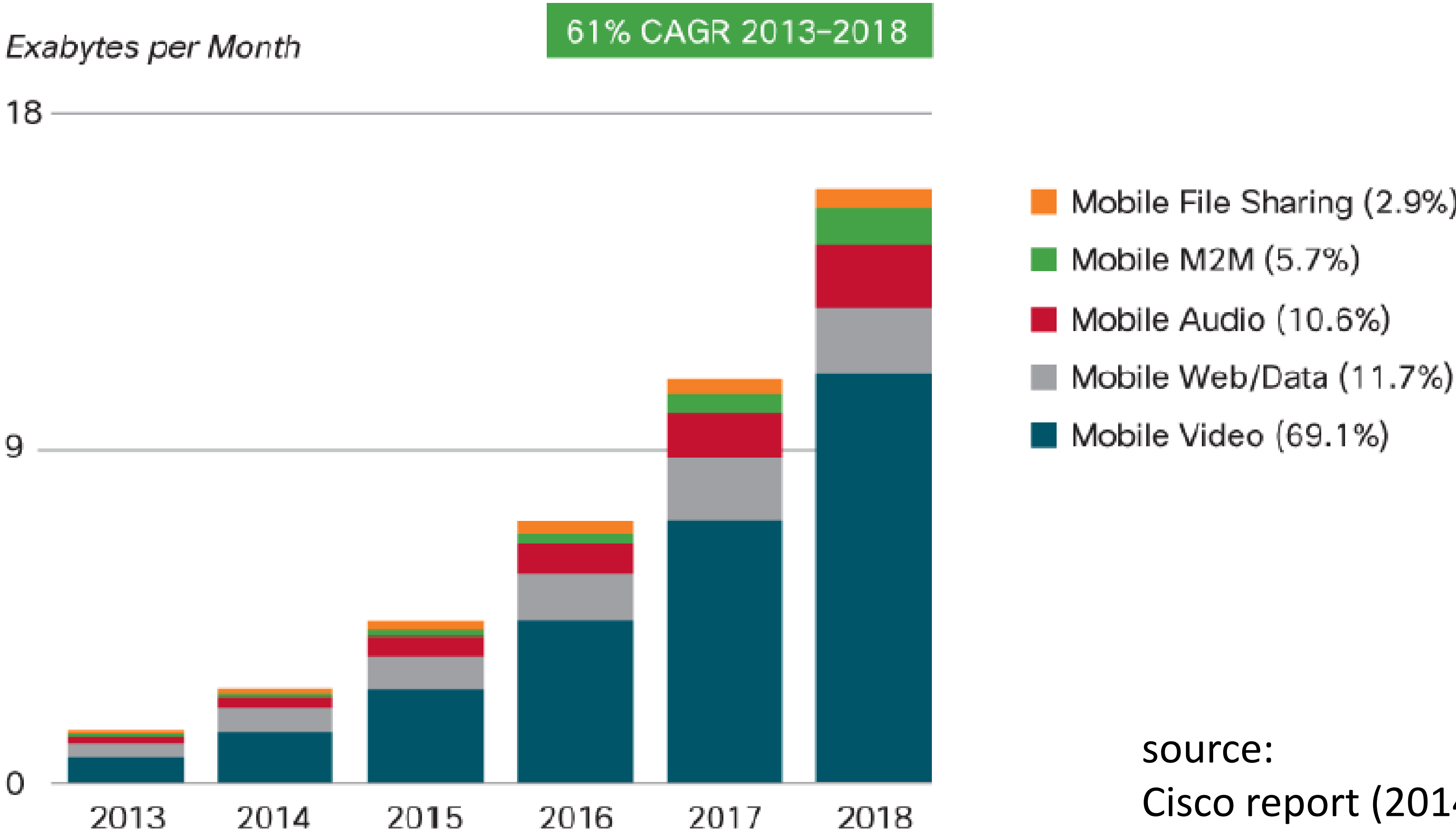
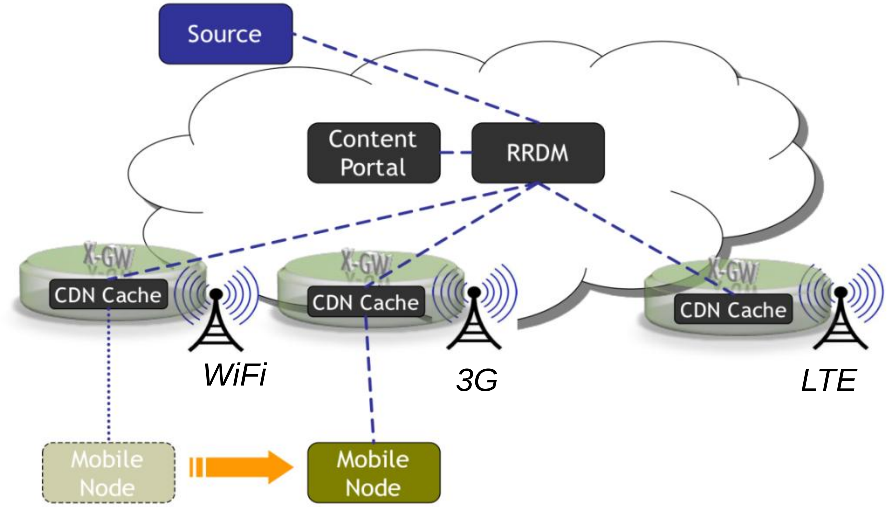
Multimedia traffic growth



source:
Cisco report (2014)

Challenges for video systems



- Heavy data
- Hierarchical system
- Backhaul network capacity
- Must handle different access techniques
- Need to account for video popularity, heterogeneous user terminals
- Quality-of-Experience of video is hard to capture

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Our approach

- We propose a way to facilitate video handling
- Proposed approach:
  - Represent video characteristics in terms of rate
  - Capture the relationship between rate and QoE
  - Use this to determine resources needed
  - Make admission decisions based on QoE
- We consider a set of video clips and apply machine learning techniques

Analysis

- We consider a test set of 38 video clips, all encoded in an H.264-AVC format
- All the videos are encoded with a 16-frame structure (1 I-frame, 15 P-frames) and compressed with 18 different quantization strategies

  Transmit rate [bit/s] of video v at compression level c: $r_v(c)$

  Rate Scaling Factor (RSF): $\rho_v(c)=\log(r_v(c)/r_v(1))$

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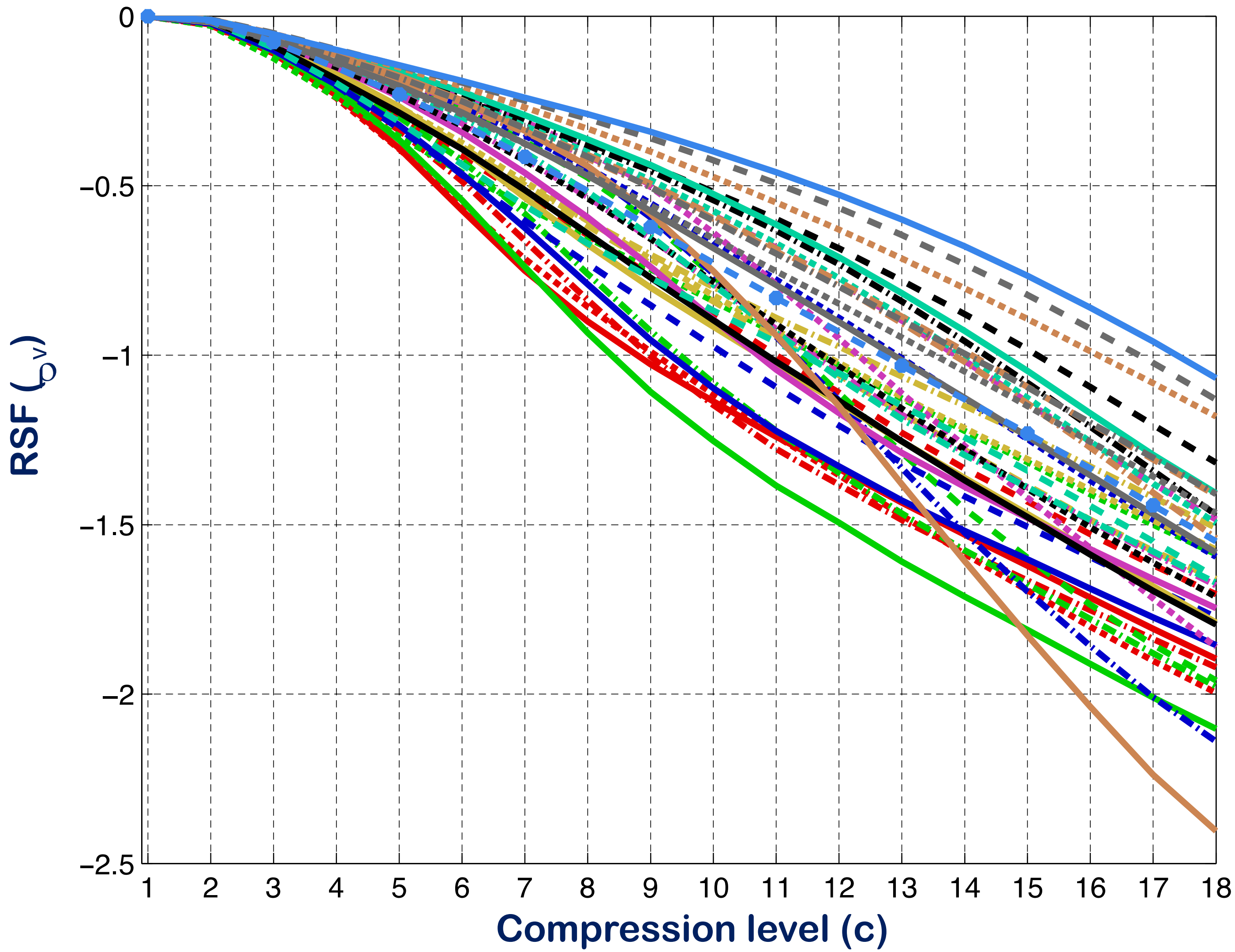
Rate Scaling Factor *vs* compression



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QoE characterization

- Depending on the content, the perceived quality of a given compression level changes
- There are several metrics to measure quality of a video signal
- Here, video quality is expressed in terms of Structural Similarity (SSIM)

SSIM	MOS	Quality	Impairment
≥ 0.99	5	Excellent	Imperceptible
[0.95, 0.99)	4	Good	Perceptible but not annoying
[0.88, 0.95)	3	Fair	Slightly annoying
[0.5, 0.88)	2	Poor	Annoying
< 0.5	1	Bad	Very annoying

Structural Similarity (SSIM)

- SSIM measures the closeness of square sets of pixels, and is computed as

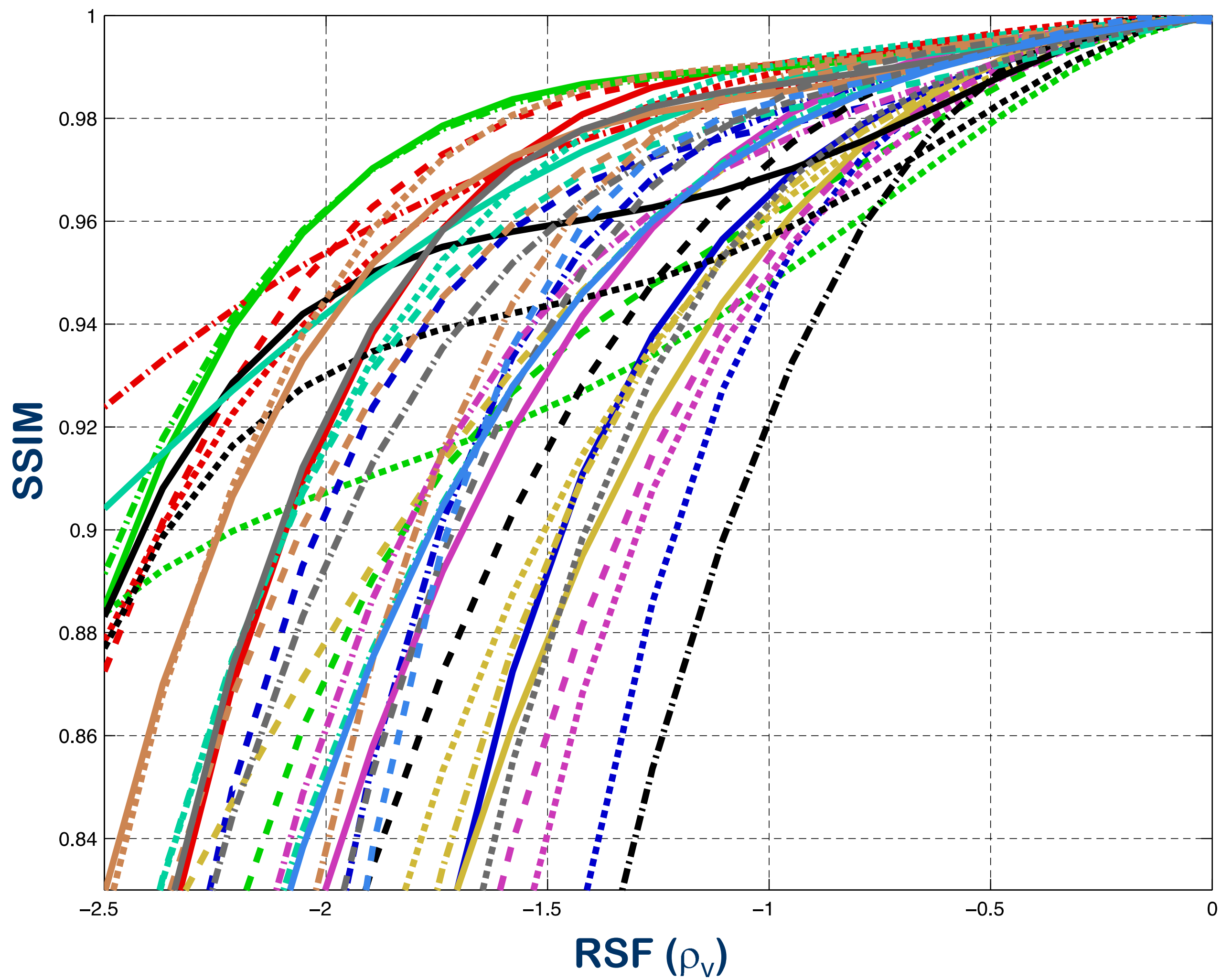
$$SSIM(X,Y) = \frac{(2\mu_X\mu_Y + c_1)(2\sigma_{XY} + c_2)}{(\mu_X^2 + \mu_Y^2 + c_1)(\sigma_X^2 + \sigma_Y^2 + c_2)} \quad (1)$$

with μ and σ^2 denoting the mean and variance of the luminance value in the corresponding window, and c_1 and c_2 being variables to stabilize the division with weak denominator

Measures image degradation in terms of perceived structural information change

Represents quality as seen by the human eye

SSIM versus RSF



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Remarks

- All the videos exhibit similar trends
  - monotonic descent
  - a steep "fall" after a threshold
- However, there are quantitative differences
  - different perceived end quality
  - different resource requirements
- These characteristics are roughly consistent within the same (homogeneous) video

SSIM polynomial approximation

- We introduce a polynomial approximation to express SSIM behavior
  - This provides a compact representation for use in VAC and RM

$$F_v^{(n)}(\rho) \simeq 1 + a_{v,1}\rho + a_{v,2}\rho^2 + a_{v,3}\rho^3 + \ldots + a_{v,n}\rho^n$$

- A 4-degree polynomial provides a quite accurate approximation of the SSIM vs RSF curve

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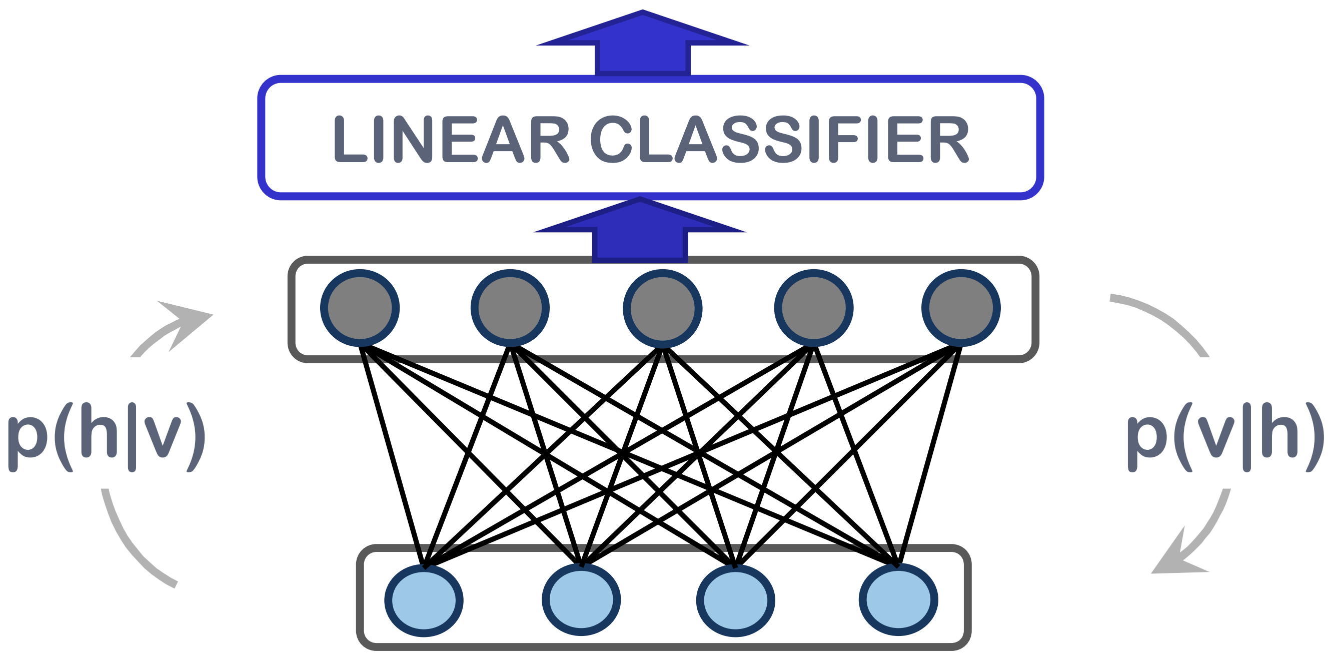
Proposed approach

Video recognition/classification/SSIM estimation



visible layer:

GoP frames' size

Proposed approach

- Input to the RBM: **frame size only**
  - This is done for a whole GoP (isolated)
  - The RBM "learns" by creating certain patterns in the hidden layer
  - This enables a sparser representation of the input in the hidden layer
- After that, we apply a linear classifier for recognition / classification / SSIM estimation
  - Note: we must train a different linear classifier for each case, while the RBM is trained just once for all

Possible video applications

- Knowledge of these characteristics of the video may be useful for

  (i) QoE-aware admission/congestion control

  (ii) estimating resources required by popular videos for better planning of replica servers

  (iii) inferring user preferences

- Two different tasks can be envisioned:

  video recognition (exactly identify it)

  video classification (just categorize it)

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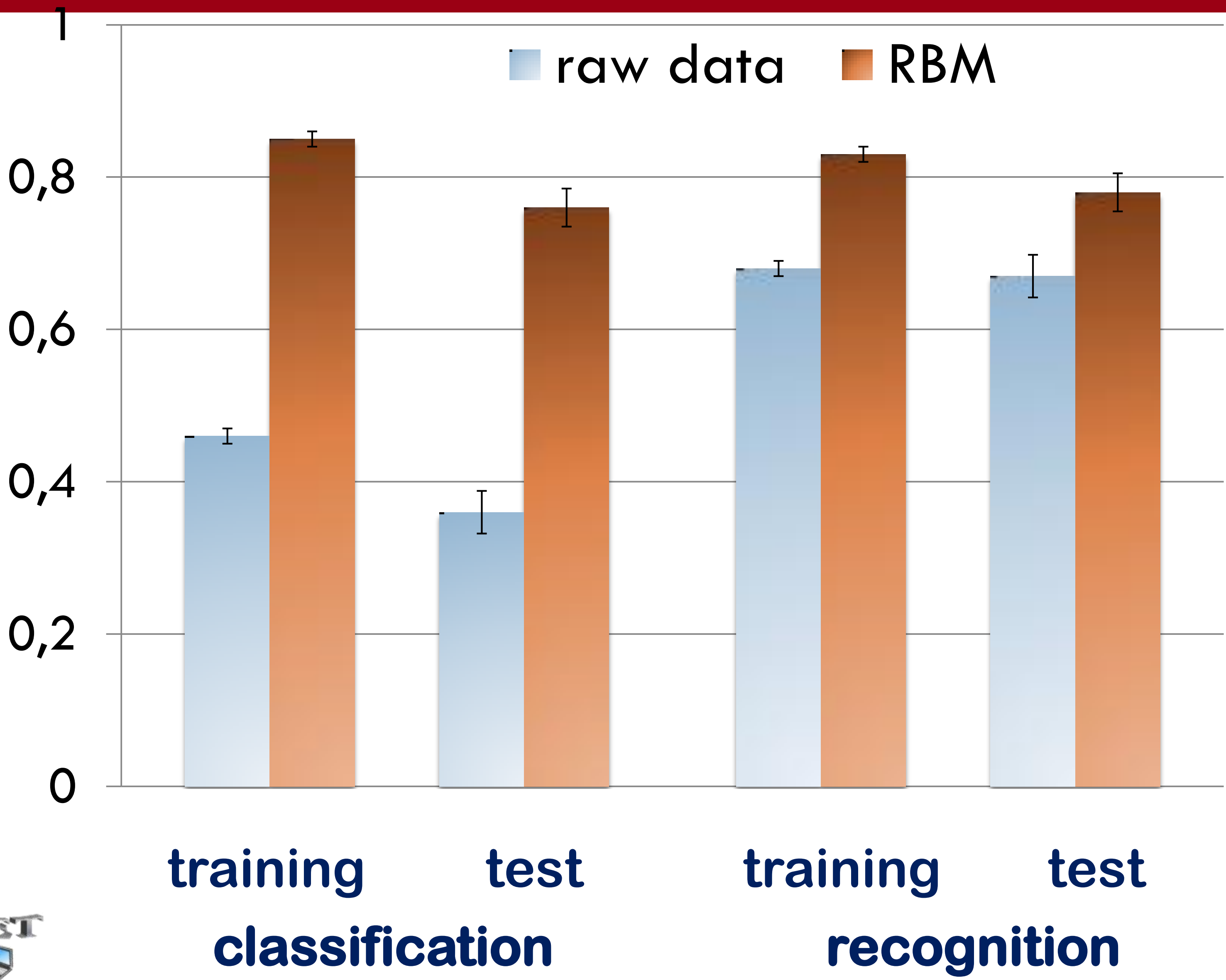
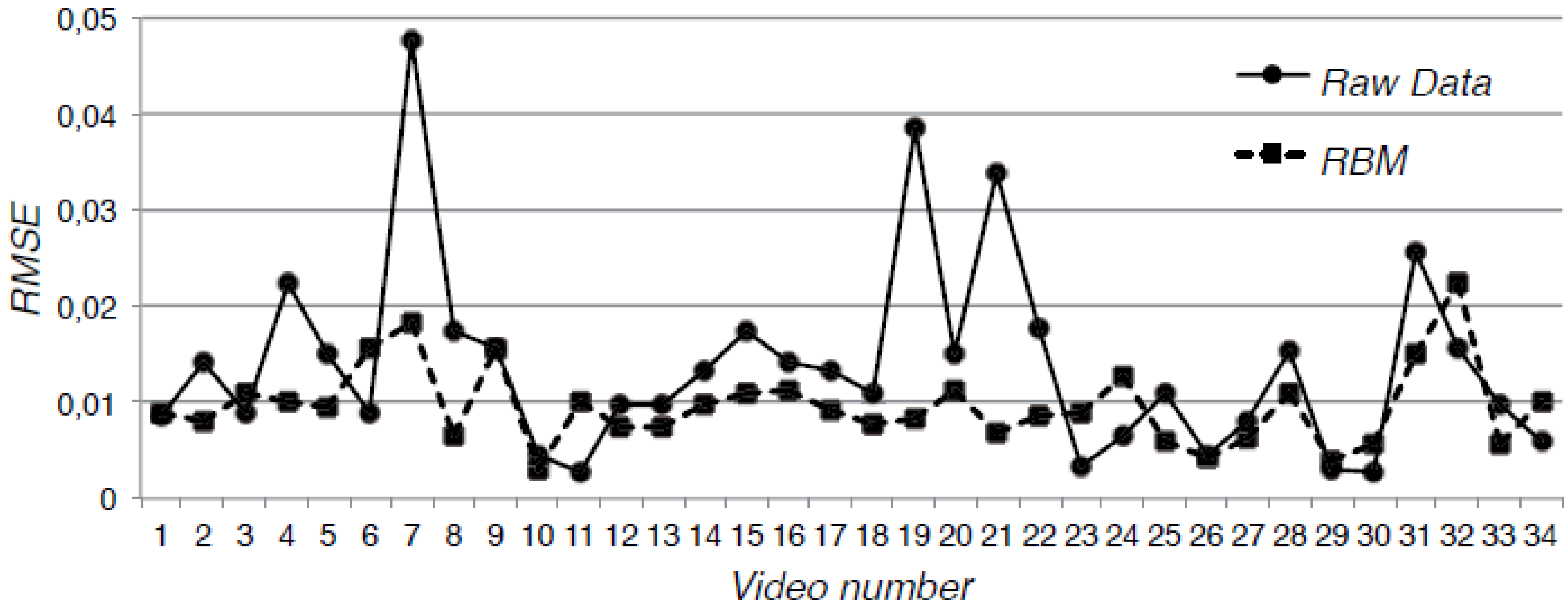
Preliminary results



Learning via RBM: accuracy

- Root Mean Square Error (RMSE) between exact SSIM and polynomial approximation with estimated coefficients



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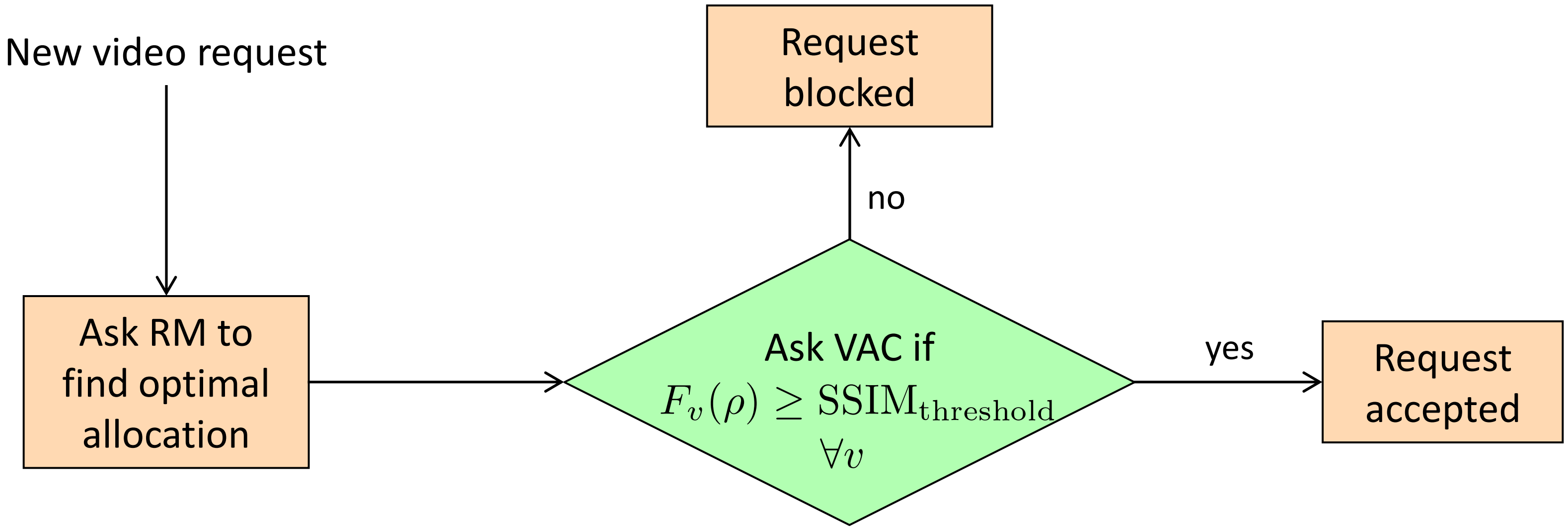
CognitiveVideo Admission Control & Resource Management

- Videos multiplexed into a shared link of capacity R
- **Resource Manager (RM)**: detects changes and triggers optimization to adapt video rates to maximize QoE utility function
- **Video Admission Controller (VAC)**: determines whether a new video request can be accepted without decreasing QoE of any video below a threshold F*

Cognitive VAC

- A proxy intercepts video requests and operates as
  - **Video Admission Controller (VAC):** determine whether a new video request can be accepted
  - **Resource Manager (RM):** adapt video rates to maximize QoE



System scenario

- Users are divided in **bronze**, **silver** and **gold** classes in increasing order of minimum guaranteed QoE

- Videos are multiplexed onto a shared link of capacity R

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The resource allocation problem

- Channel allocation vector

$$\Gamma = \{\gamma_v\}$$

- The optimization problem addressed by RM is:

Resource share allotted to video "v"

$$\Gamma_{\text{opt}} = \underset{\Gamma}{\operatorname{argmax}}\, \overbrace{U(\Gamma, R, \{F_v\})}^{\text{Utility function}} \quad \text{s.t.} \quad \sum_v \gamma_v \le 1$$

Rate allocation vector

Channel rate

SSIM videos' characteristics

Rate Fairness (RF)

$$\gamma_{\mathrm{opt},v} = \frac{r_v(1)}{\sum_j r_j(1)}$$

$$\Downarrow$$

Each video flow gets a channel share directly proportional to its full quality bitrate

SSIM Fairness (SF) – the idea

$$U(\Gamma, R, \{F_v\}) = \min_v \left(F_v(\tilde{\rho}_v) - F^*_{q(v)}\right)$$

where $q(v) \in \{1, 2, 3\}$ is the class of the user watching the vth video flow and $F^*_{q(v)}$ is the SSIM threshold relative to class $q(v)$

$$\Downarrow$$

Each video flow has the same increase α wrt the minimum quality level imposed to its class

If α=0.01, the SSIM of videos belonging to the three classes will be:

Class	SSIM
Gold (F*=0.98)	0.99
Silver (F*=0.95)	0.96
Bronze (F*=0.9)	0.91

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Simulation setup

- Poisson video requests (0.1 req./s)
- Exponential video duration, mean 100 s
- Average offered load of $0.1 \cdot 100 = 10$ videos
- QoE for each class:

Class	Minimum SSIM	Approximate target MOS
Gold	0.98	5
Silver	0.95	4
Bronze	0.9	3

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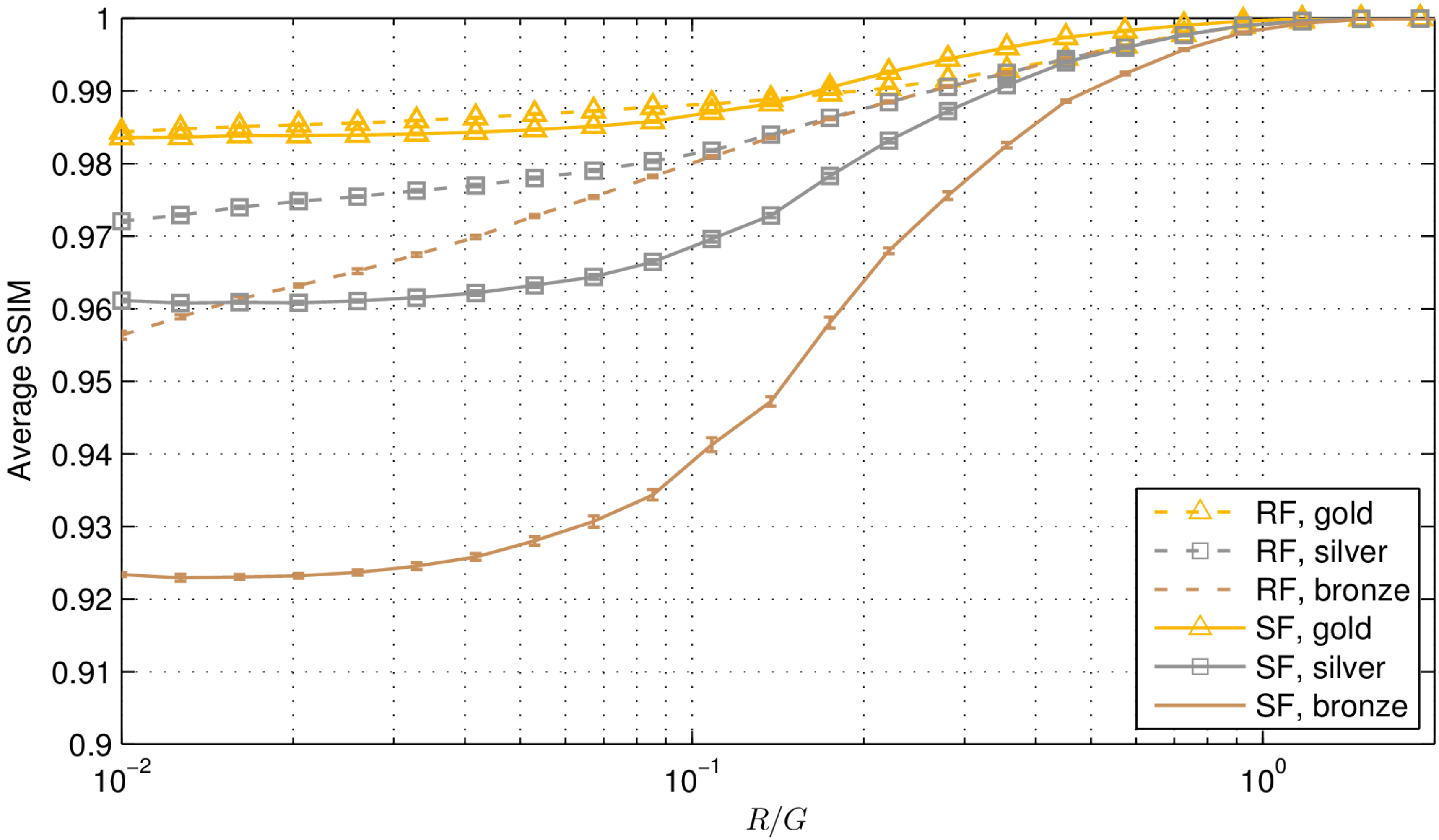
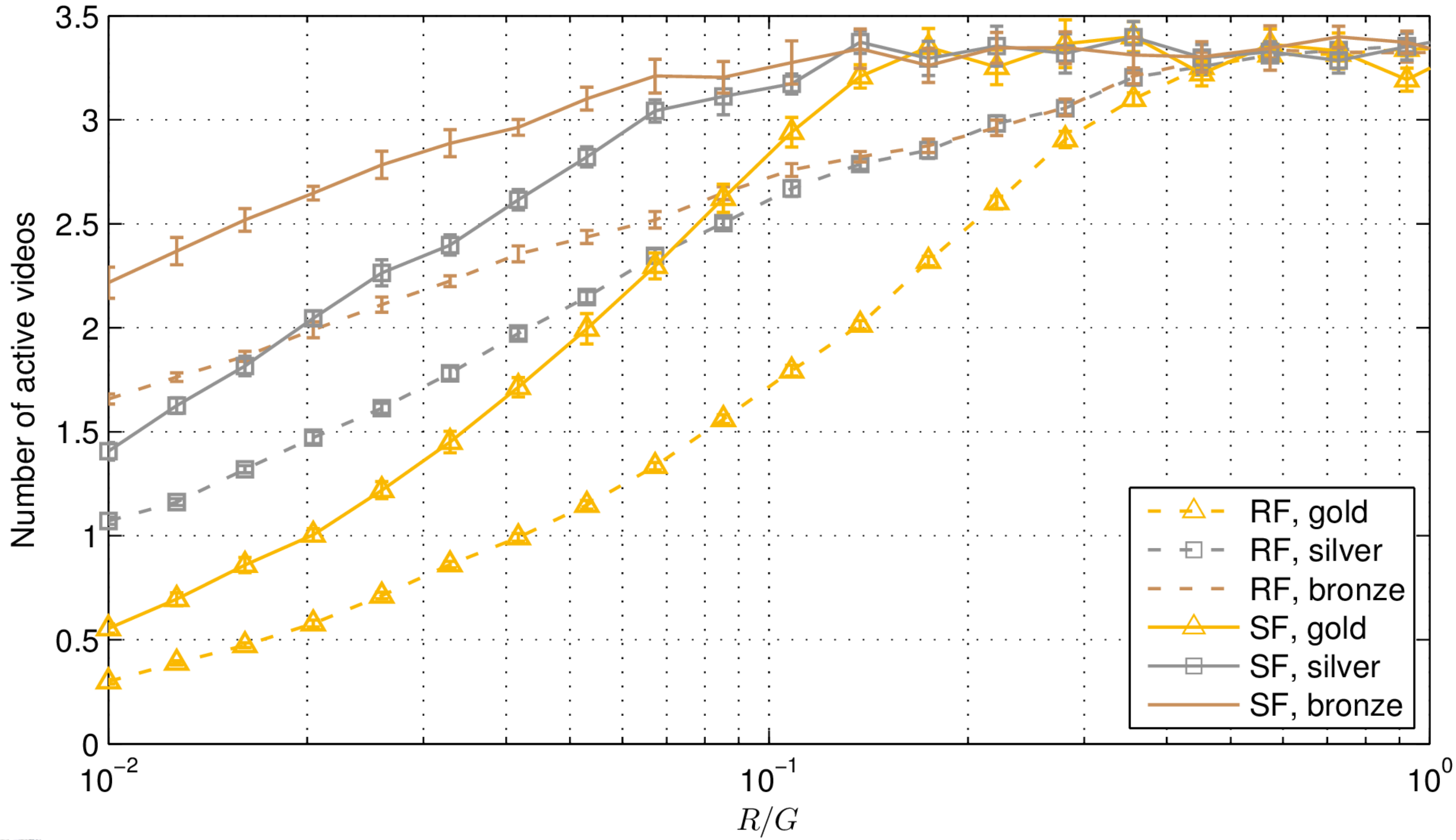
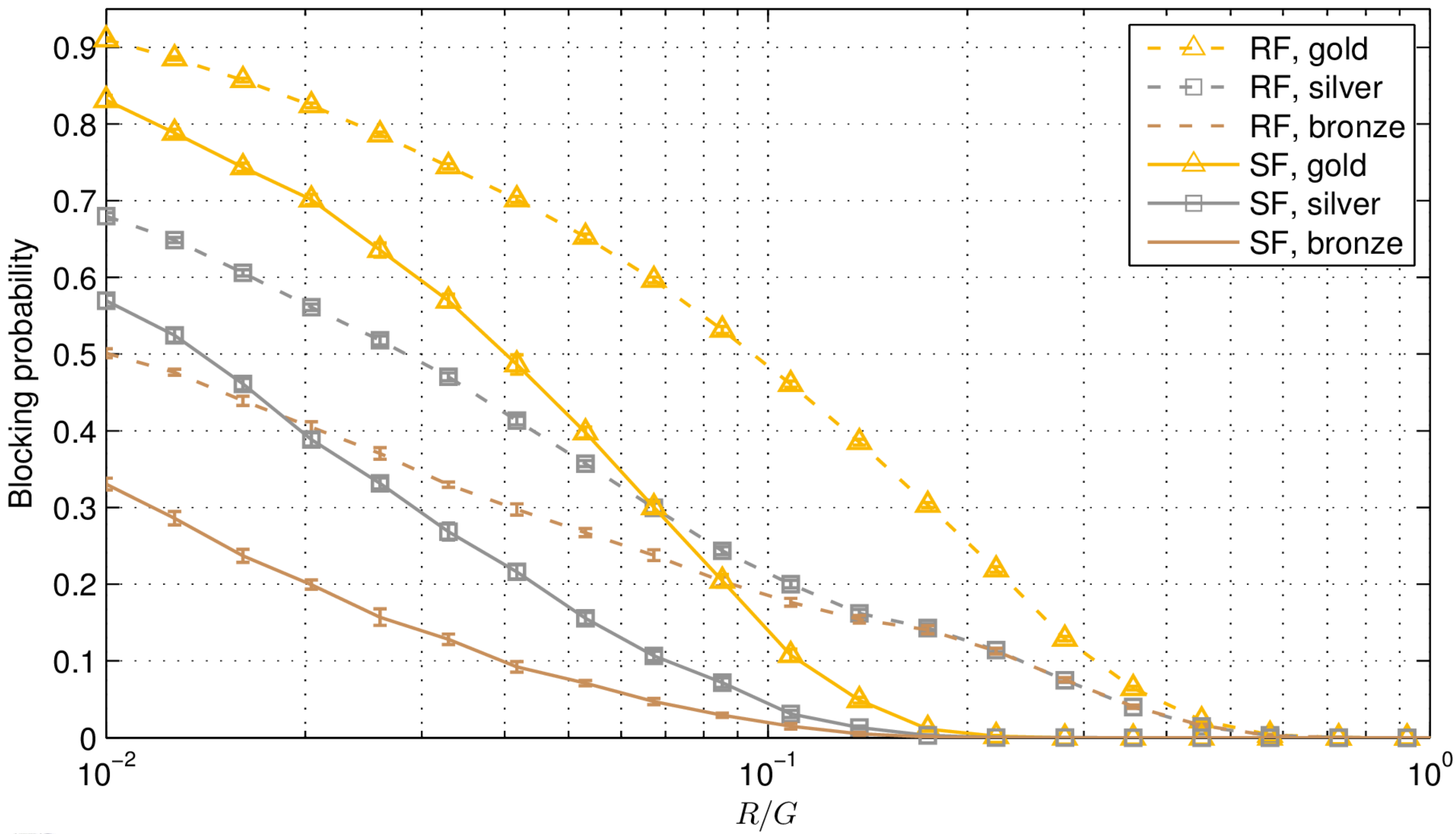
Average SSIM



Number of active videos



Blocking probability



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Conclusions

- Optimizing resource allocation for video transmission is challenging
  - many numerical parameters involved
  - subjective QoE issues
  - high signaling exchange
- We designed a framework for resource allocation that does not need prior models
- Simulations show that QoE-aware strategies outperform QoE-agnostic video admission techniques in terms of QoE delivered and admitted videos

Publications

- Daniele Munaretto, Andrea Zanella, Daniel Zucchetto, Michele Zorzi, "Data-driven QoE optimization techniques for multi-user wireless networks" in the Proceedings of the 2015 International Conference on Computing, Networking and Communications, February 16-19, 2015, Anaheim, California, USA

- Alberto Testolin, Marco Zanforlin, Michele De Filippo De Grazia, Daniele Munaretto, Andrea Zanella, Marco Zorzi, Michele Zorzi, "A Machine Learning Approach to QoE-based Video Admission Control and Resource Allocation in Wireless Systems" in the Proceedings of IEEE IFIP Annual Mediterranean Ad Hoc Networking Workshop, Med-Hoc-Net 2014, June 2-4, 2014, Piran, Slovenia.

- Leonardo Badia, Daniele Munaretto, Alberto Testolin, Andrea Zanella, Marco Zorzi, Michele Zorzi , "Cognition-based networks: applying cognitive science to multimedia wireless networking" in the Proceedings of Video Everywhere (VidEv) Workshop of IEEE WoWMoM'14, 16 June, 2014, Sydney, Australia.

- Marco Zanforlin, Daniele Munaretto, Andrea Zanella, Michele Zorzi, "SSIM-based video admission control and resource allocation algorithms" in the Proceedings of WiOpt workshop WiVid'14, May 12-16, 2014, Hammamet, Tunisia.