Experimental QoE evaluation of multicast video delivery over IEEE 802.11aa WLANs

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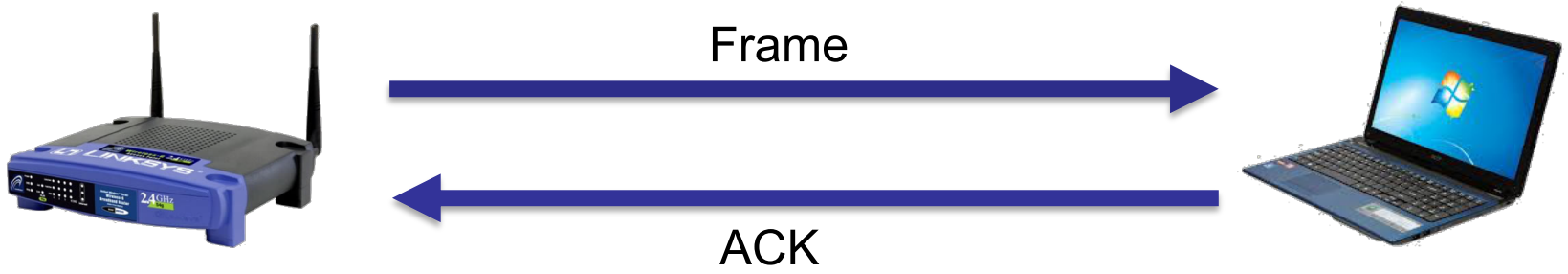
Real-Time Multicast: some use cases

- Wireless set-top boxes
- Enhanced driving
  - Intersections
  - See through (trucks)
- Crowded scenarios

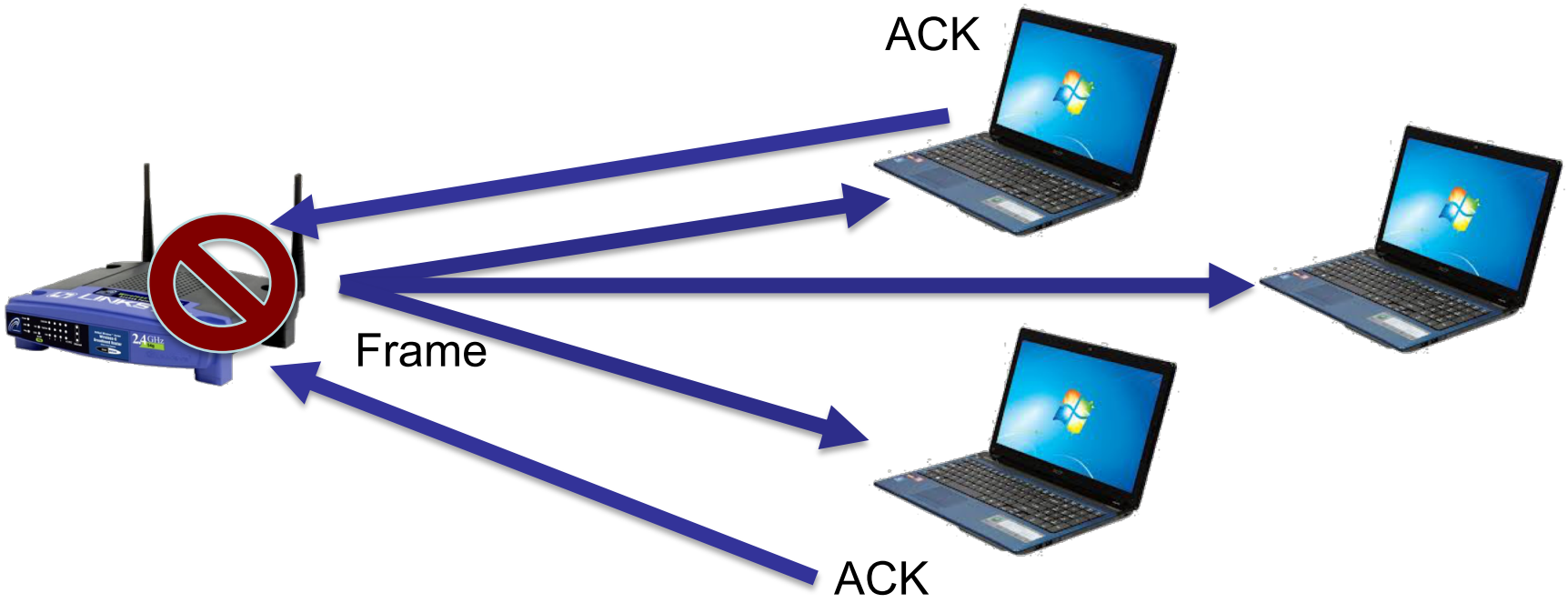
WiFi - 802.11 Unicast channel access

- Distributed Coordination Function (DCF)
  - Based on CSMA/CA with binary exponential back-off
    - Waits for channel to be idle
    - Transmits a frame and wait for acknowledgement
  - **Reliability** through ARQ



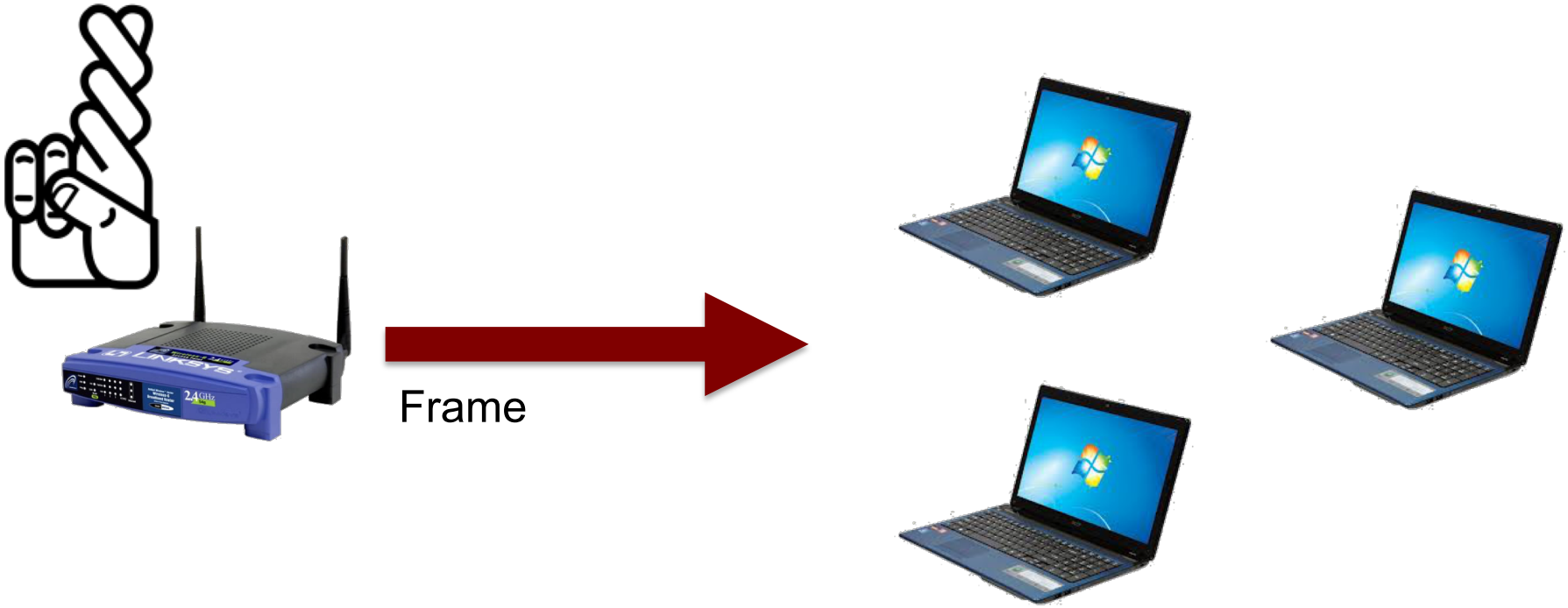
802.11 Multicast (1997)

- Challenge: reliability to a set of receivers is relatively complex



802.11 Multicast (1997)

- "Solution": use a **robust** rate, hope for the best

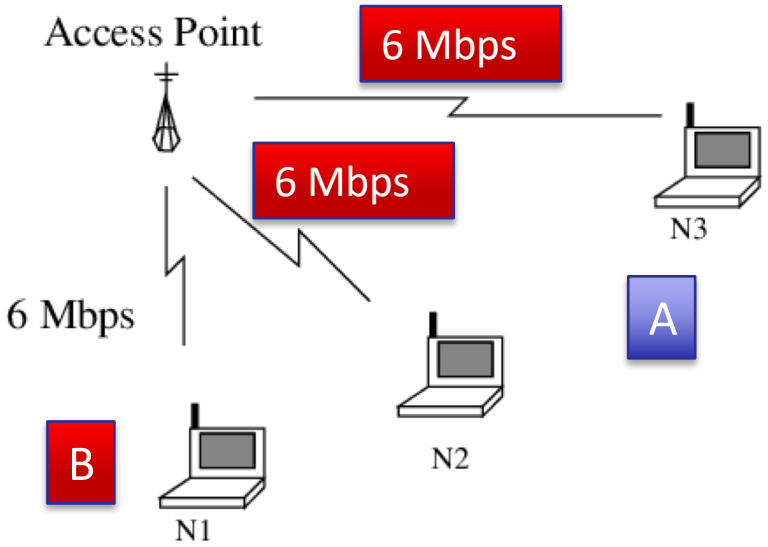


Main issues with this approach (1/2)

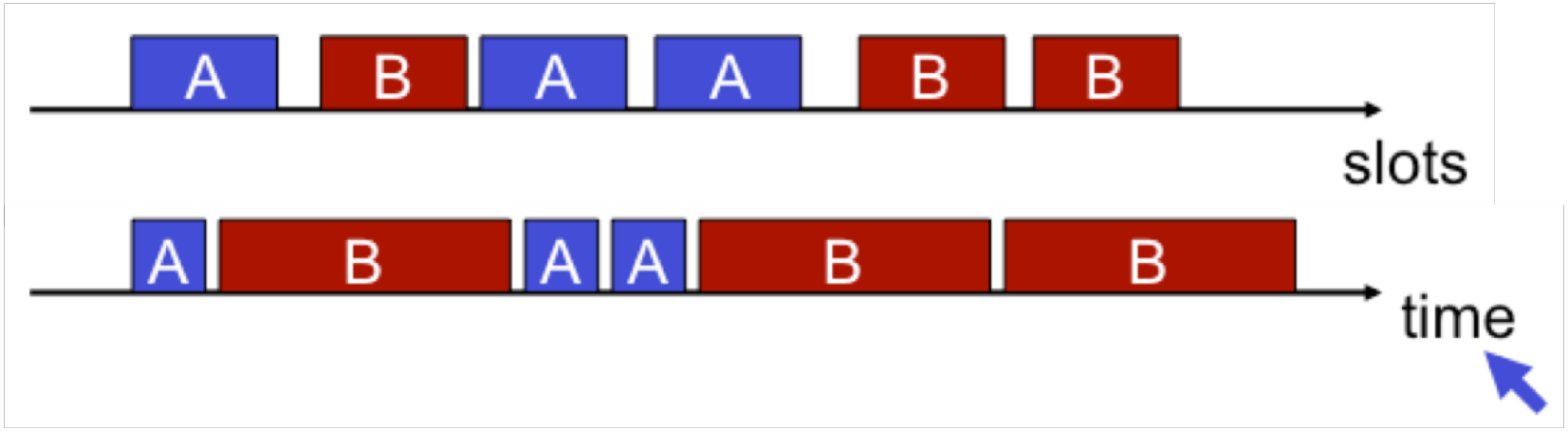
- Reliability is not guaranteed
  - Not necessarily a *terrible* thing for multimedia

Main issues with this approach (2/2)

- *Performance anomaly*
  - Lower Modulation and Coding Scheme dominates the performance



- Fair channel access:



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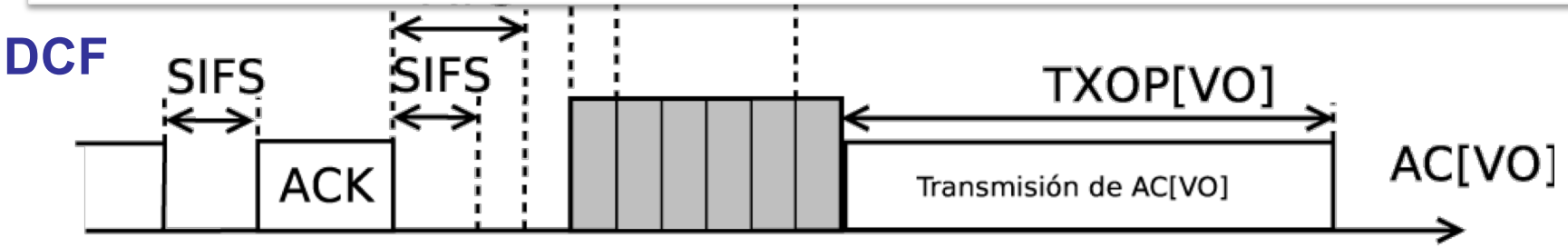
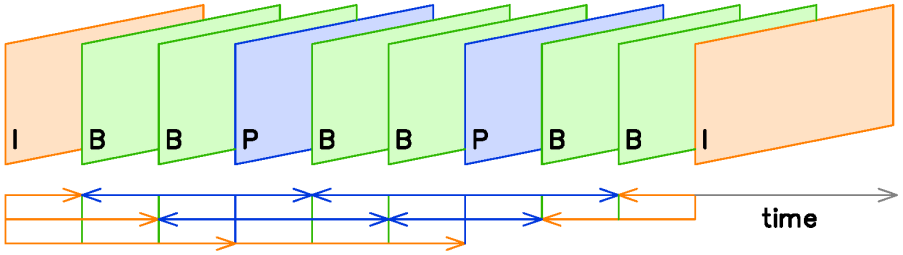
Enhancements over time: prioritization and efficiency

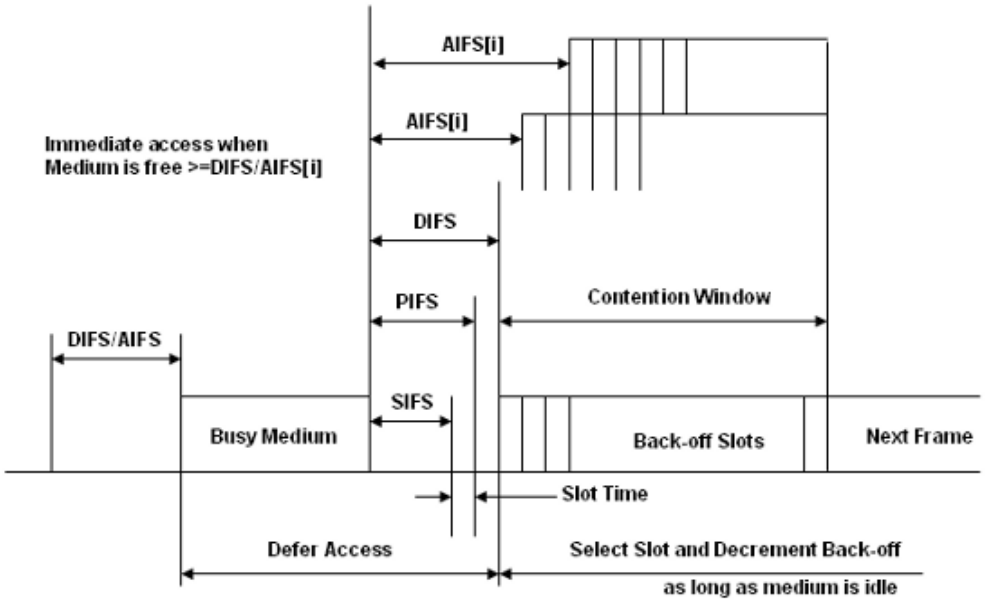
Inter-station prioritization: EDCA

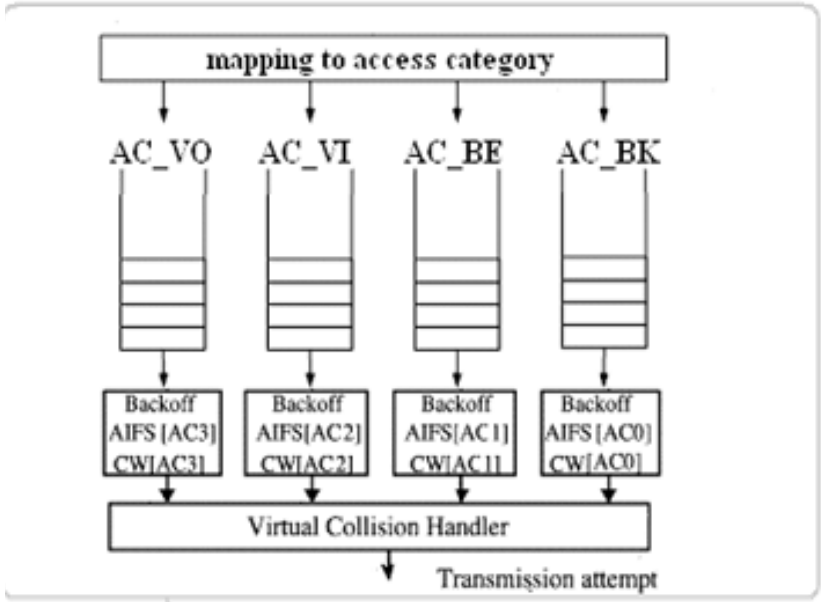


Intra-station prioritization

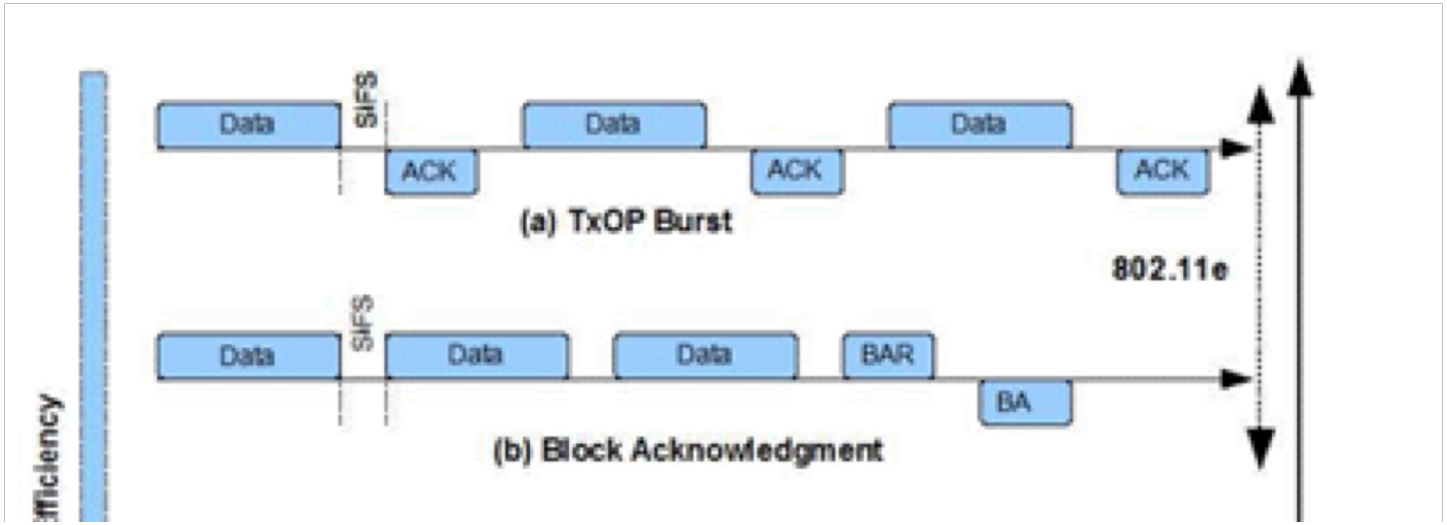
- 802.11e – EDCA
  - Different queues







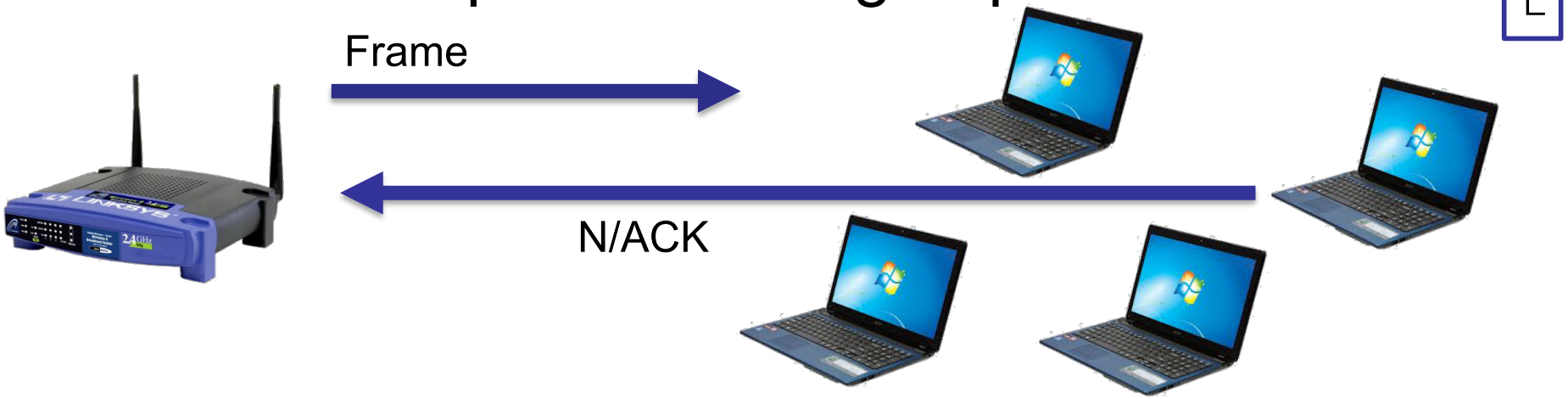
TXOP - Bursts



Both enhancements: unicast traffic

Research community: LBM

- Leader-based multicast
  - One STA represents the group behavior



- Challenges
  - Leader selection (algorithm, signaling)
  - Mobility, updates

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IEEE 802.11aa

IEEE 802.11aa

- Definition of the mechanisms to support “Robust streaming of Audio Video Transport Streams”
  - Included in the release 802.11-2016 (December)

- Main features
  - (i) a ‘stream classification service’
    - intra-flow prioritization
  - (ii) interworking with IEEE 802.1AVB
    - for end-to-end reservations
  - (iii) Overlapping Basic Service Set (OBSS) management
  - **(iv) Group Addressed Transmission Service**

Directed Multicast Service

- Use DCF for unicast delivery to each destination
  - From a single stream (multicast) to many (unicast)
- Standard access: exponential backoff!
  - No prioritization over other traffic
- **Reliability** builds on DCF

Unsolicited Retries

- Similar to legacy service without MCS limit
- **Reliability** builds on preemptive **R** (re)transmission
  - Open loop, does not use feedback from receivers

ReTx Frame 58

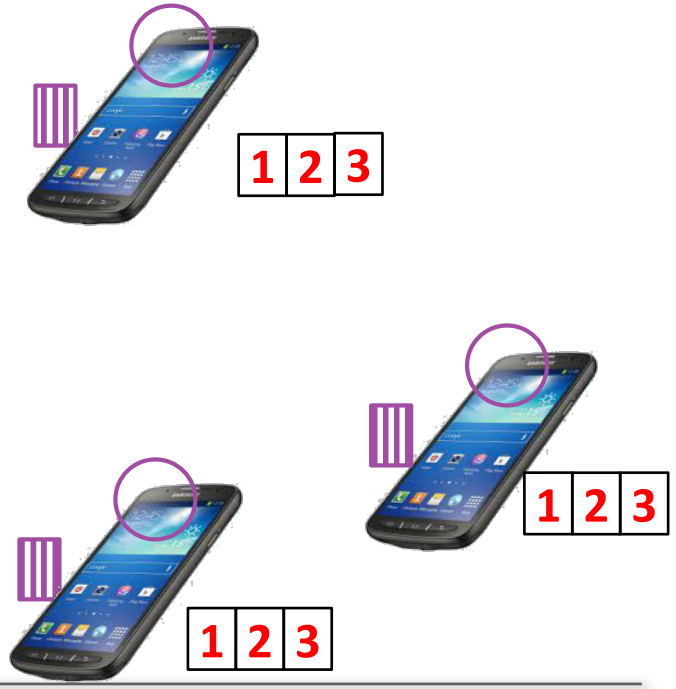
Frame 58

Frame 58

Frame 58

Block Acknowledgement

- Frames sent in (configurable length **M**) bursts
  - Really multicast delivery to Groupcast address
- Feedback (Block-Ack) collected with unicast polls
  - Block-Ack-Request(BAR) followed by Block-Ack(BA)



Implementation: lines of code

Scheme	Mode	Kernel	FW	K+F	Total
DMS	TX	149	0	0	149
	RX	0	0	0	
UR	TX	50	16	66	104
	RX	21	17	38	
BA	TX	577	618	1.190	1.632
	RX	132	341	473	

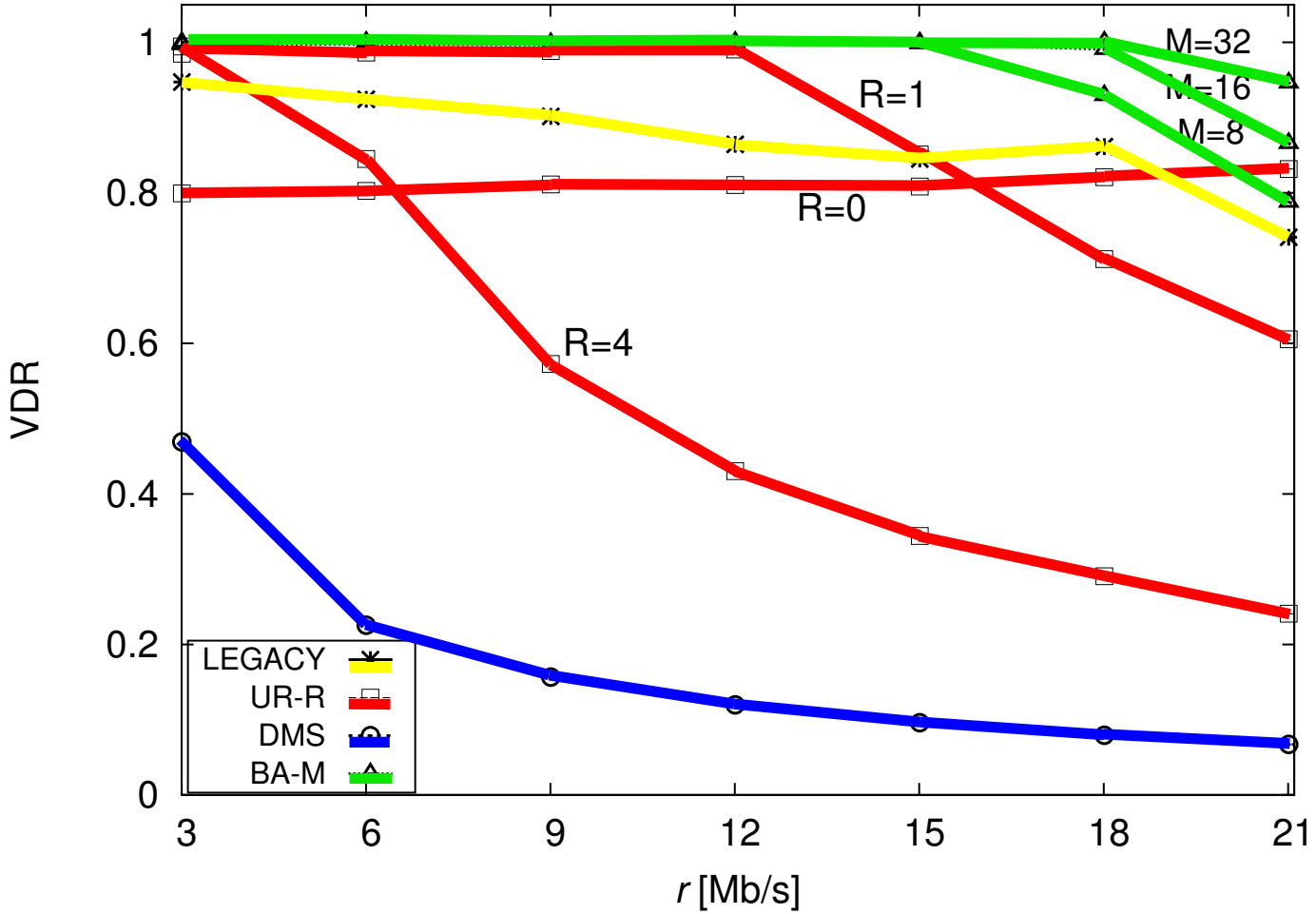
http://netweb.ing.unibs.it/~openfwwf/GATS.php

Performance Validation

- Multicast is CBR,
  - Tx rate “r”
  - 10 multicast receivers
- 10 saturated data STA
  - LP = 1400 B
- MCS:
  - Legacy & Control: 24Mb/s
  - Data: 54Mb/s

P. Salvador, L. Cominardi, F. Gringoli, P. Serrano, “A First Implementation and Evaluation of the IEEE 802.11aa Group Addressed Transmission Service,” ACM Computer Communication Review, vol. 44, no. 1, January 2014

Video delivery rate, interference-free



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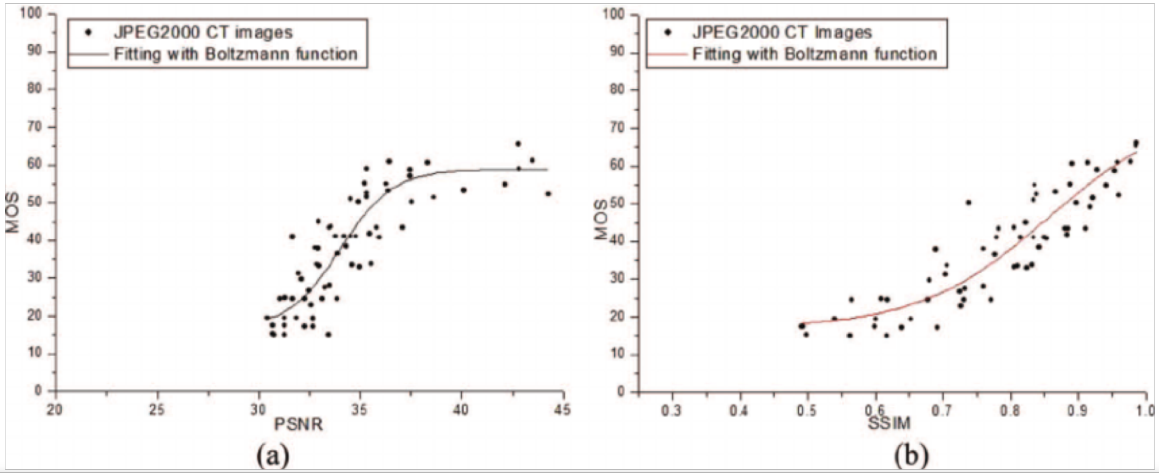
Subjective evaluation

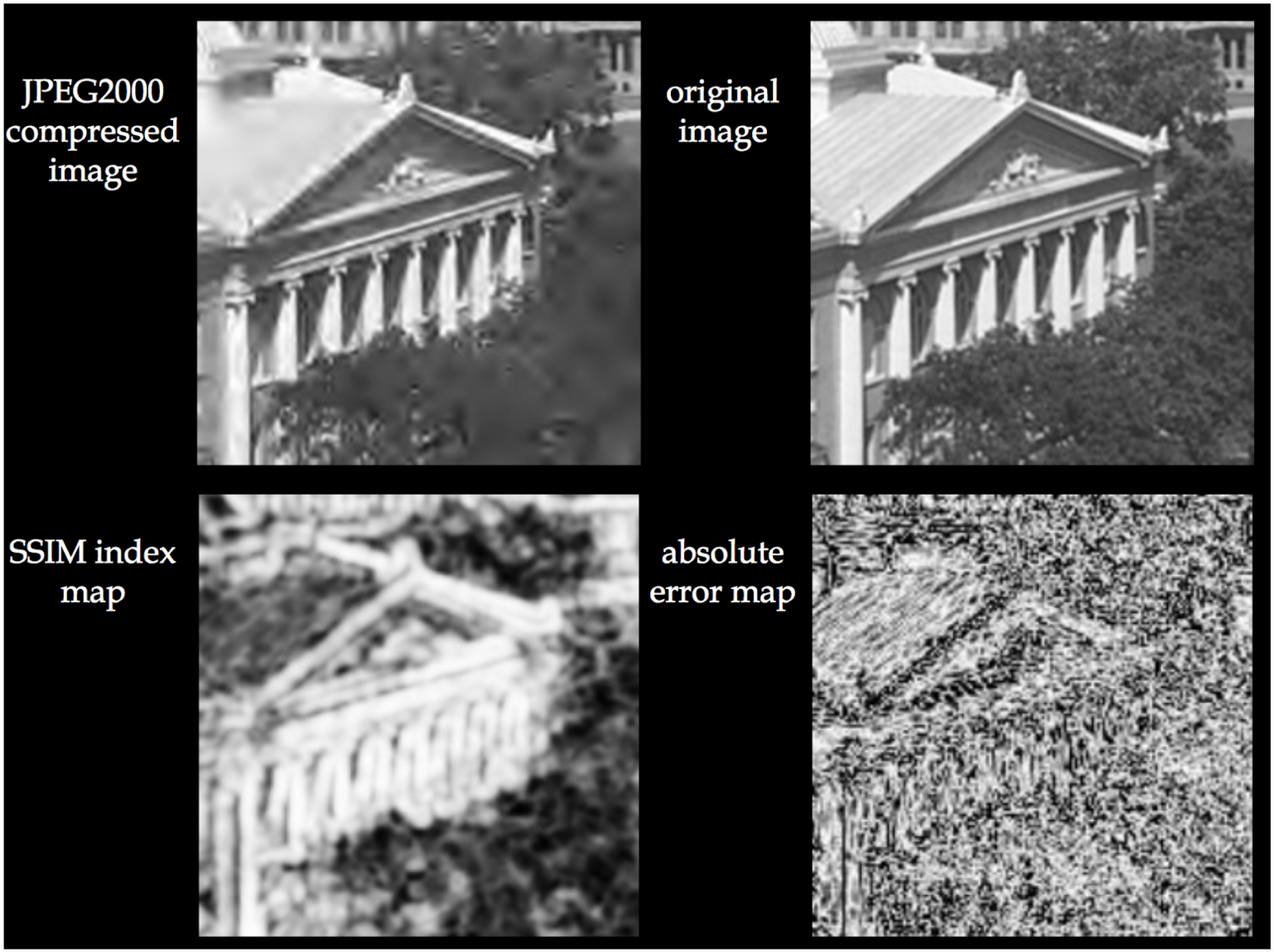
Subjective evaluation: metric

- Mean Opinion Scores (MOS) are impractical
  - QoE-oriented: MSE, PSNR
- **Structural** Similarity (SSIM) index
  - Full reference metric, originally proposed to quantify the distortion between 2 images
  - Equal to 1 if two images are identical, and becomes smaller as distortion increases

B Kumar, S P Singh, A Mohan, A Anand, "Novel MOS prediction models for compressed medical image quality," Journal of Medical Engineering & Technology, Mar 2011



On the SSIM

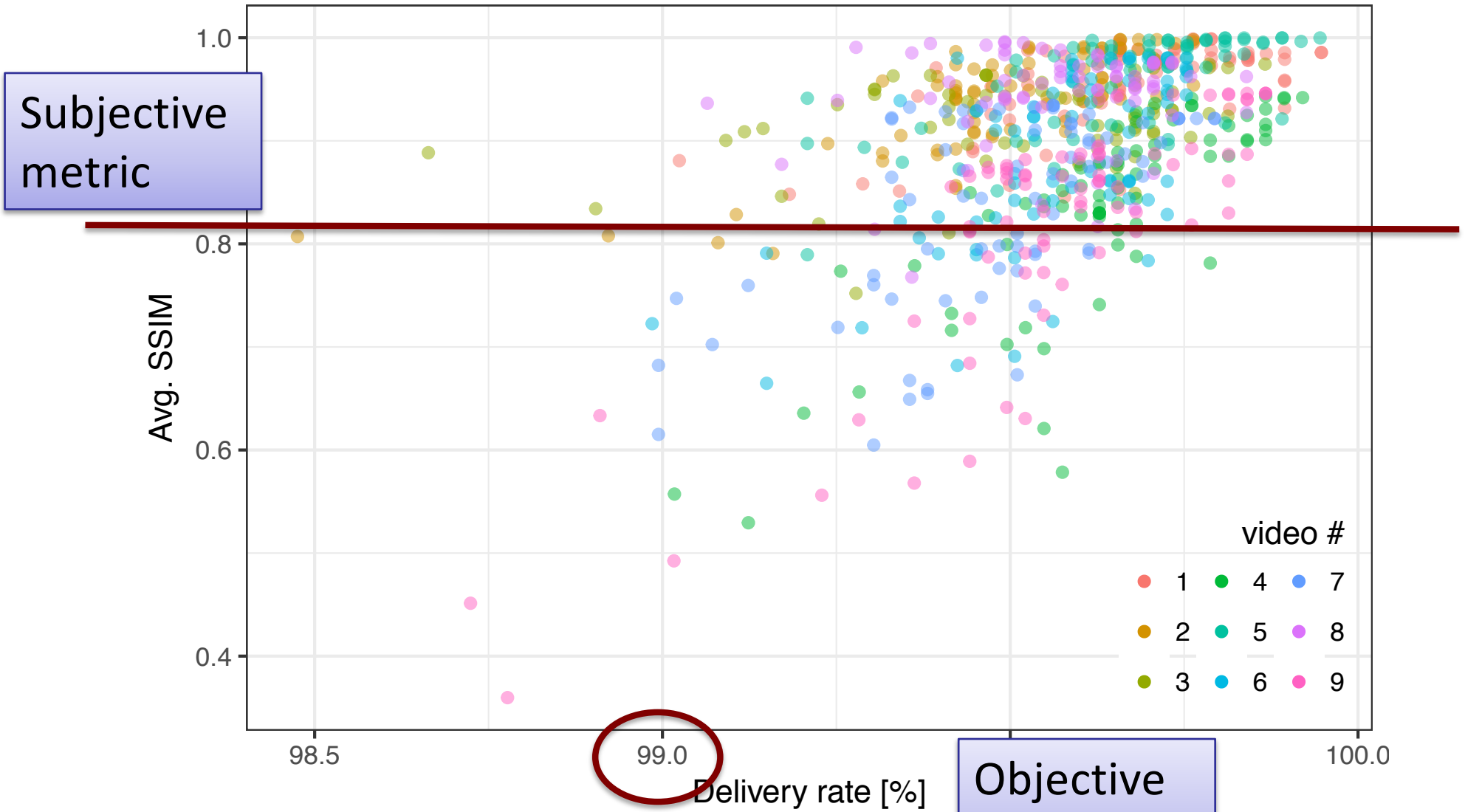

JPEG2000 compressed image
original image
SSIM index map
absolute error map

SSIM for video

- The SSIM index can also be used to assess video quality by performing a frame-by-frame comparison and averaging the results
  - 30 fps, 10'' -> N = 300 frames
  - Need to sync the frames
  - Compute the average (CPU intensive)

$$\overline{SSIM} = \frac{1}{N}\sum_{n=1}^{N} SSIM(\text{frame}_n^{\text{orig}}, \text{frame}_n^{\text{recov}})$$

QoE-based evaluation



Methodology

- Original videos (~1.1 GB)
  - 10 s videos at 30 fps, HDTV 1080p
  - Uncompressed, size of approx. 1.07 GB
- Encoding: GOP of 2 s, target rate: 4 Mb/s

	Description	Encoded size
1	Red Kayak	5.45 MB
2	Ode to the West Wind	5.45 MB
3	Double End Bag	5.65 MB
4	Go Football	5.03 MB
5	Mr. Fins, Segment 2	4.80 MB
6	Halftime Music at Game	5.37 MB
7	Burn Close-up	5.40 MB
8	Zoom Out Showing Bottles	5.15 MB
9	Scarlet Oak Easy	5.20 MB

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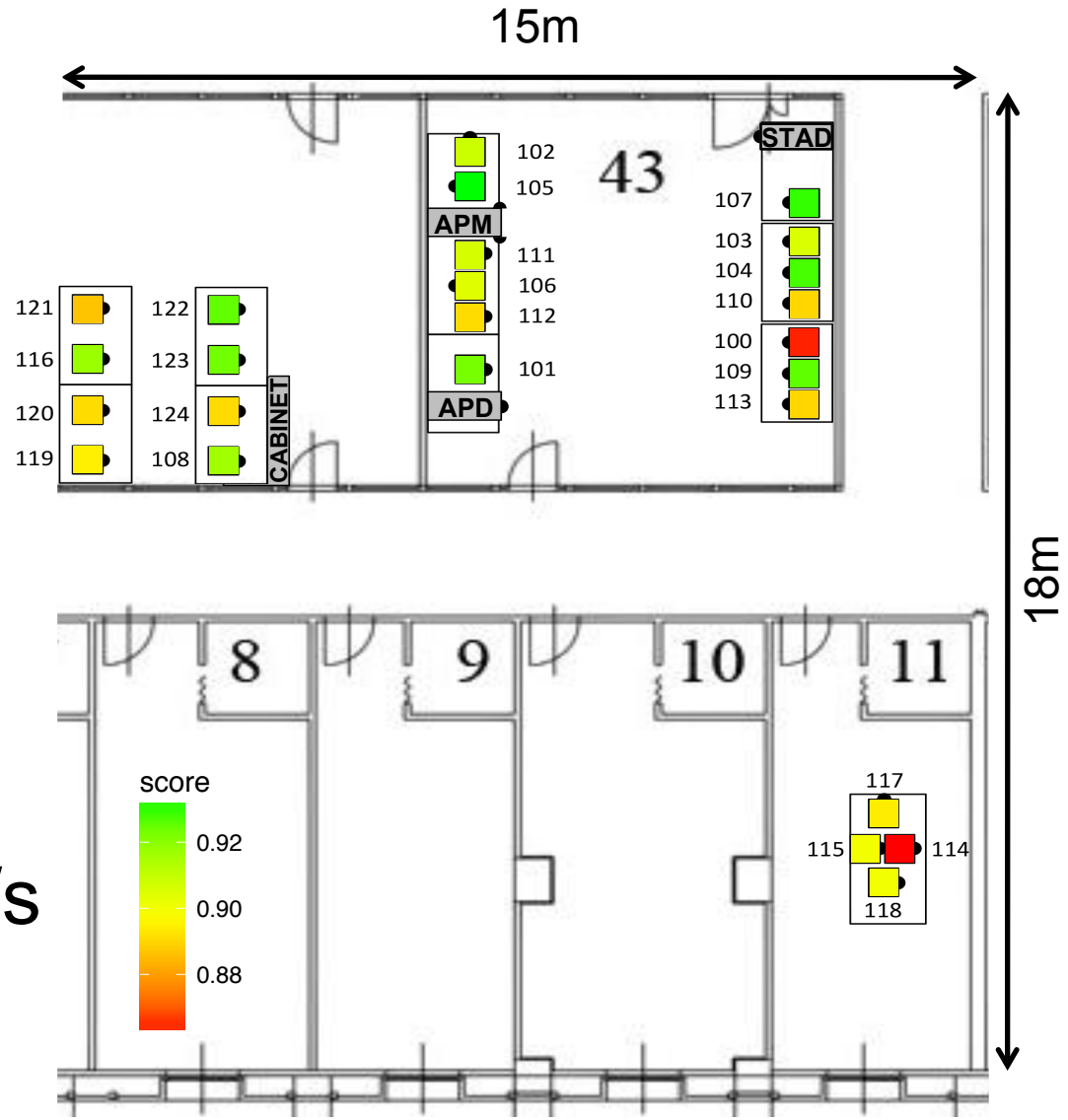
Controlled scenarios

Testbed – Univ. Brescia

- Video
  - One AP
  - 25 STA
- Data
  - One AP
  - One STA
- Color: link quality
  - 1: 100% @ 54 Mb/s
  - 0: 0%



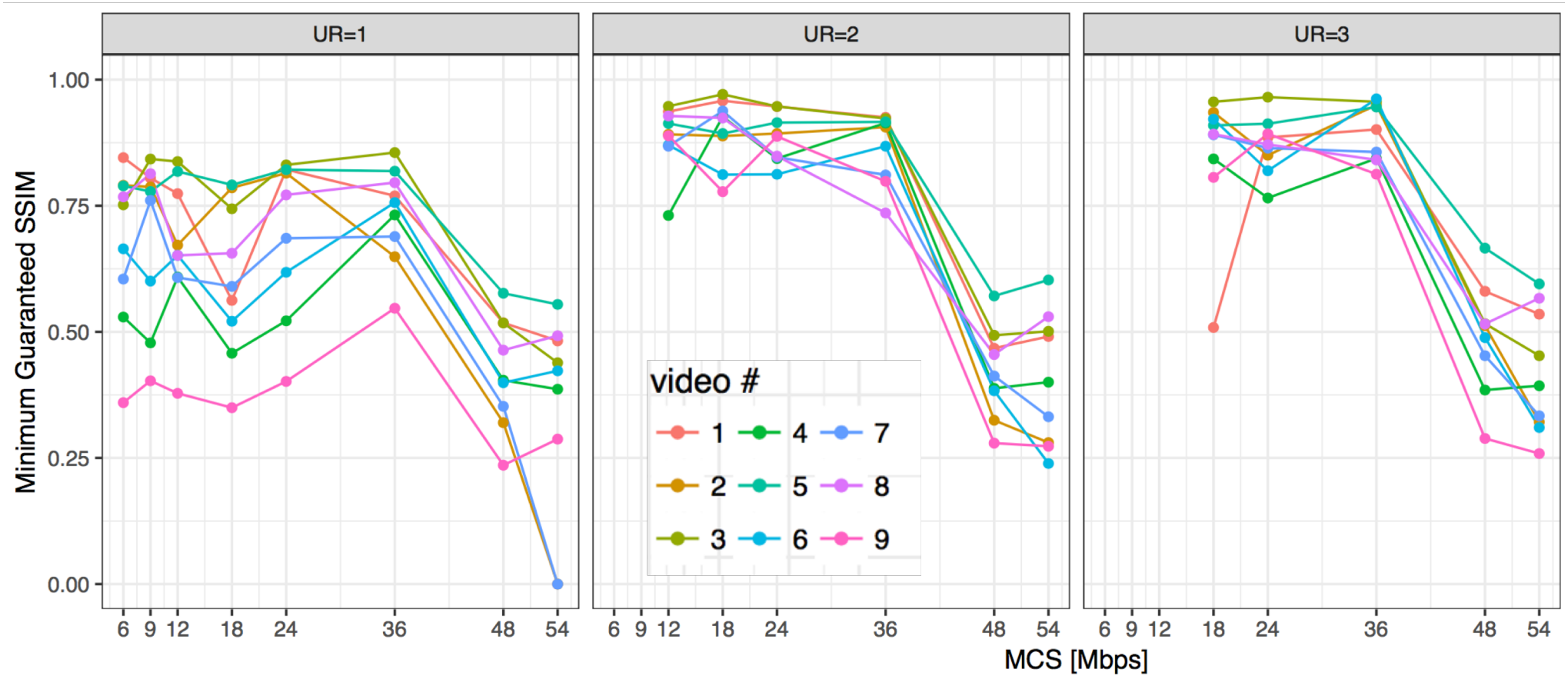
GATS evaluation under ideal conditions

- No interference
- UR = 1, 2, 3,
- BA: M = 32 frames
- MCS = {6, … 54} (If possible)

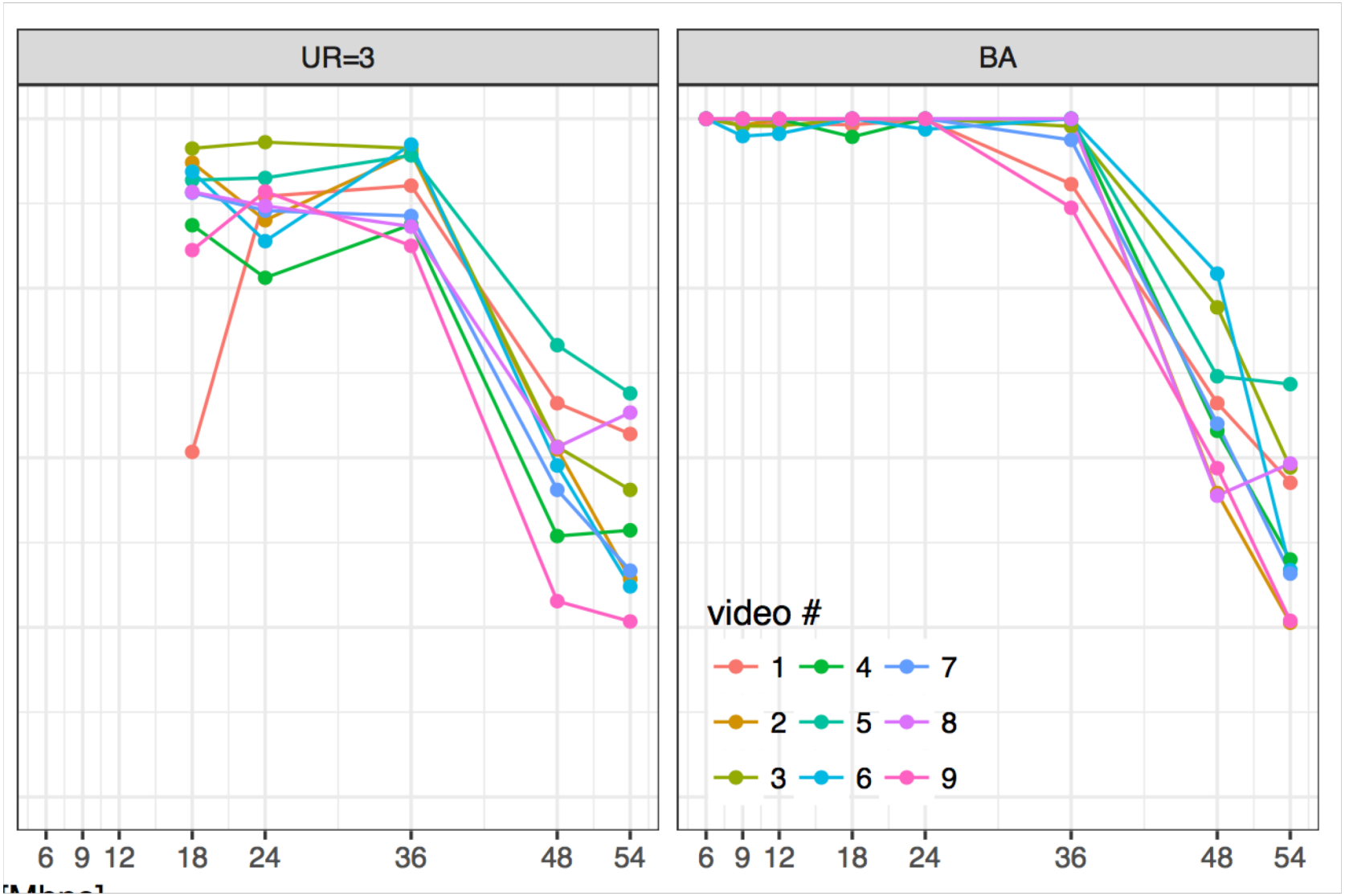
- Performance metric: guaranteed QoE
  - Stream video ‘j’ to stations, worst performing:

$$\overline{SSIM}^j = \min\{\overline{SSIM}^j_1, \overline{SSIM}^j_2, \ldots, \overline{SSIM}^j_{25}\}$$

UR, ideal conditions



BA, ideal conditions



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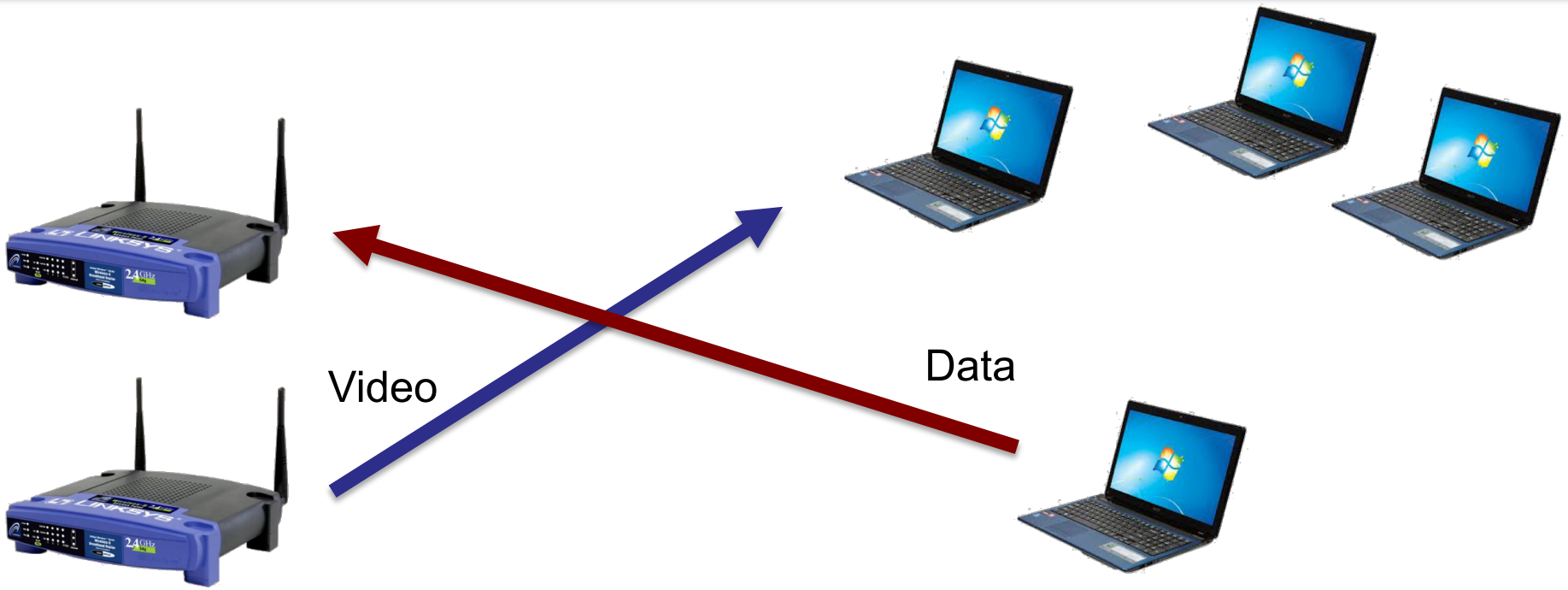
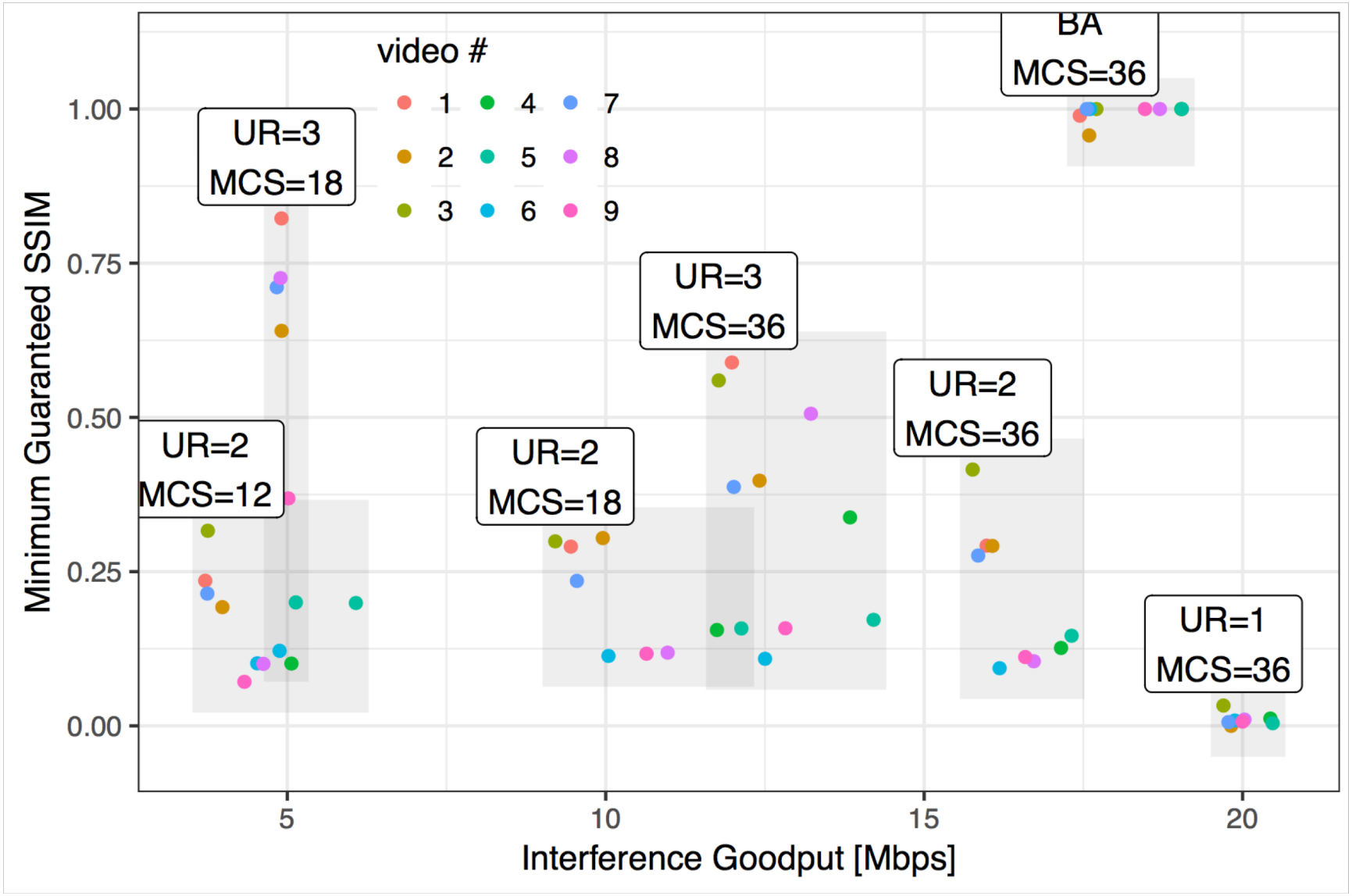
TCP, EDCA and Performance in the Wild

TCP interference – No EDCA



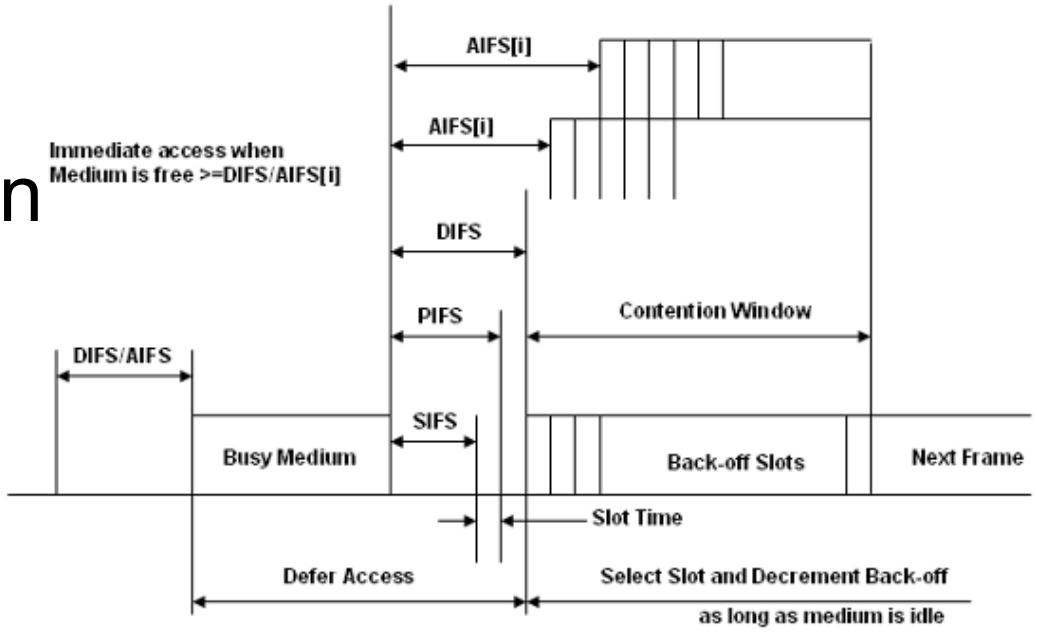
- SSIM for the 9 videos vs.
- TCP throughput

TCP interference – GATS in a nutshell



Impact of EDCA

- Multicast
  - Video configuration
- Data
  - Best effort conf.

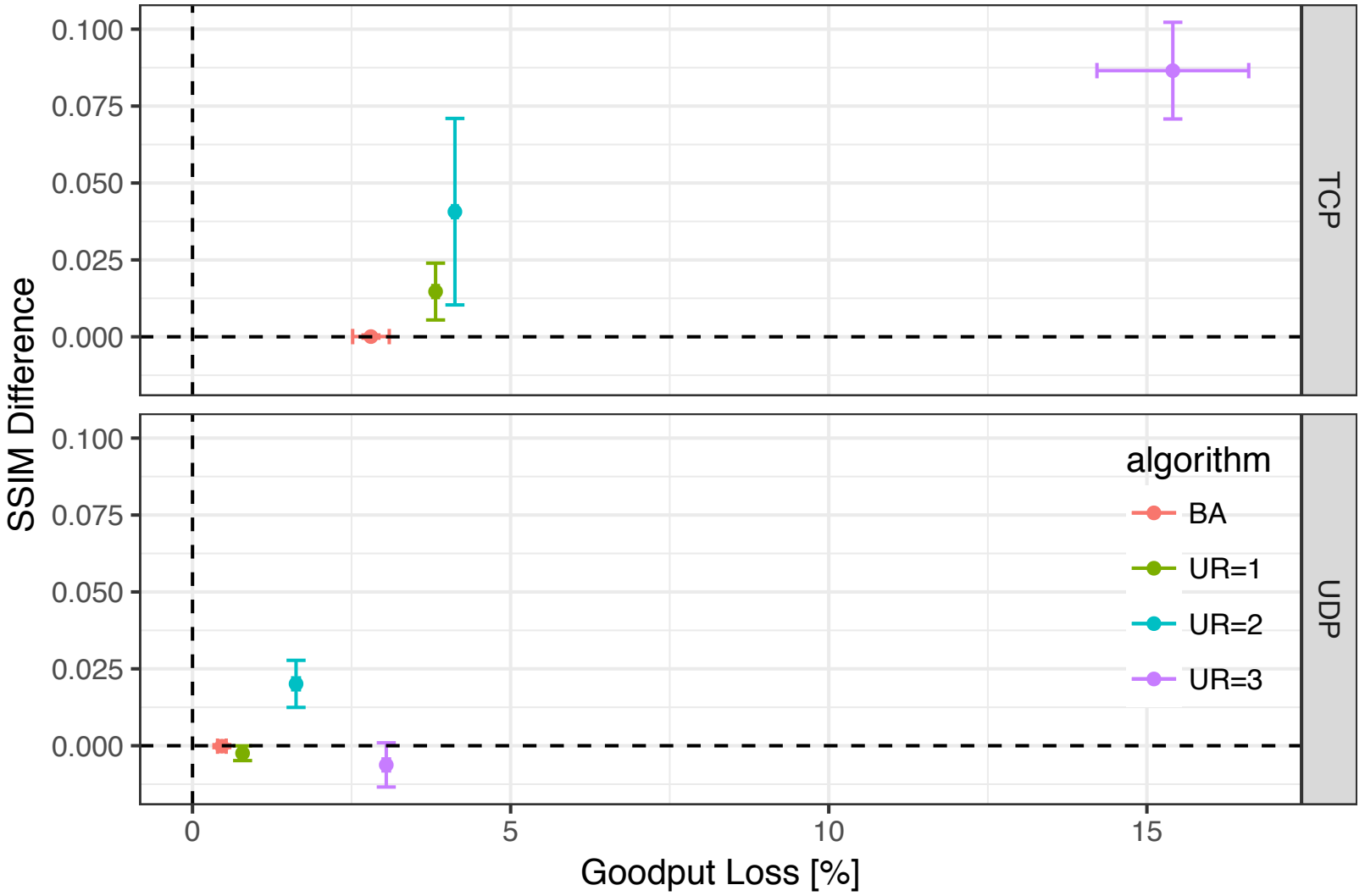


- Difference between experiments:

$$\text{SSIM difference} = \text{SSIM(EDCA)} - \text{SSIM(DCF)}$$

$$\text{Goodput loss} = \frac{\text{Goodput(DCF)} - \text{Goodput(EDCA)}}{\text{Goodput(DCF)}}$$

Impact of EDCA - little

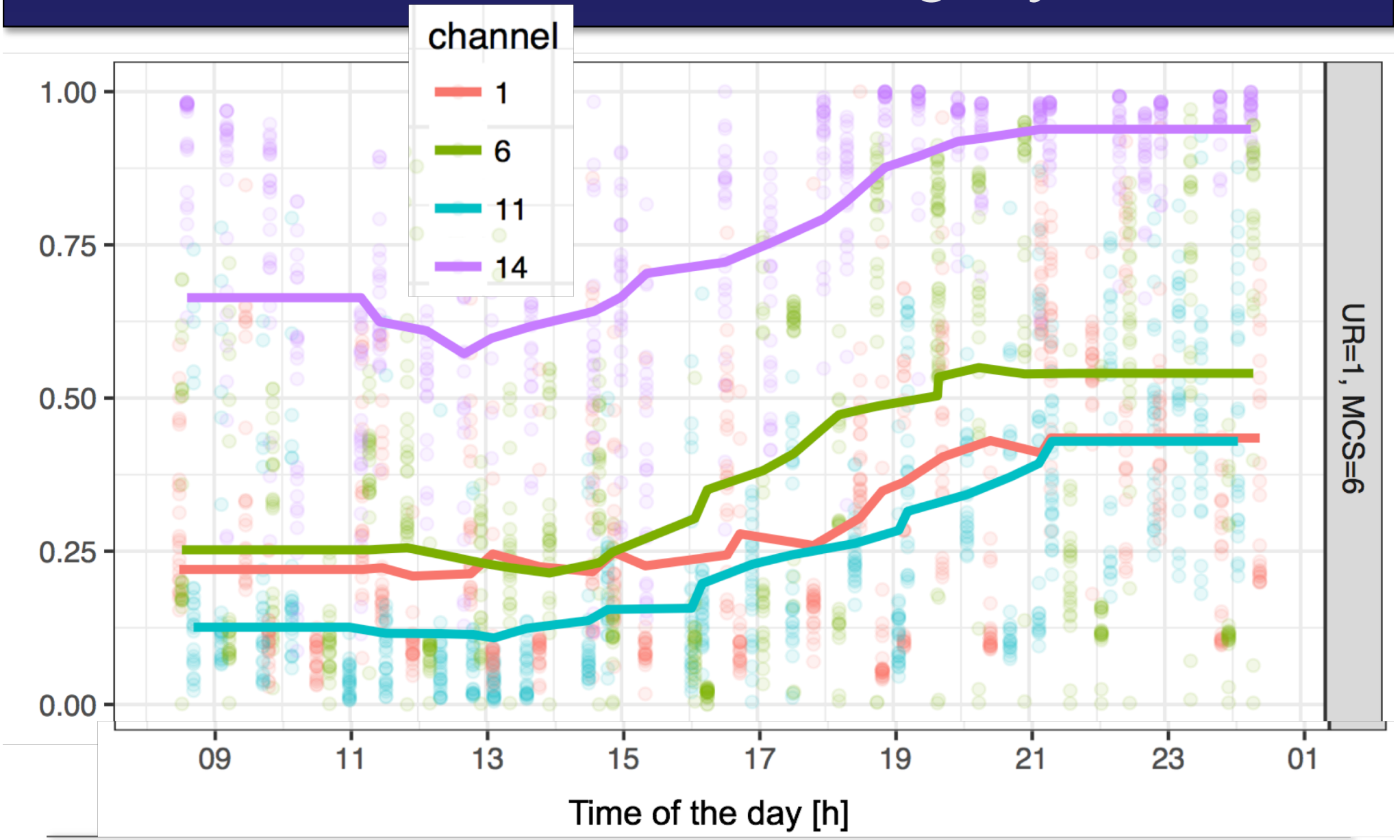


Performance in the wild

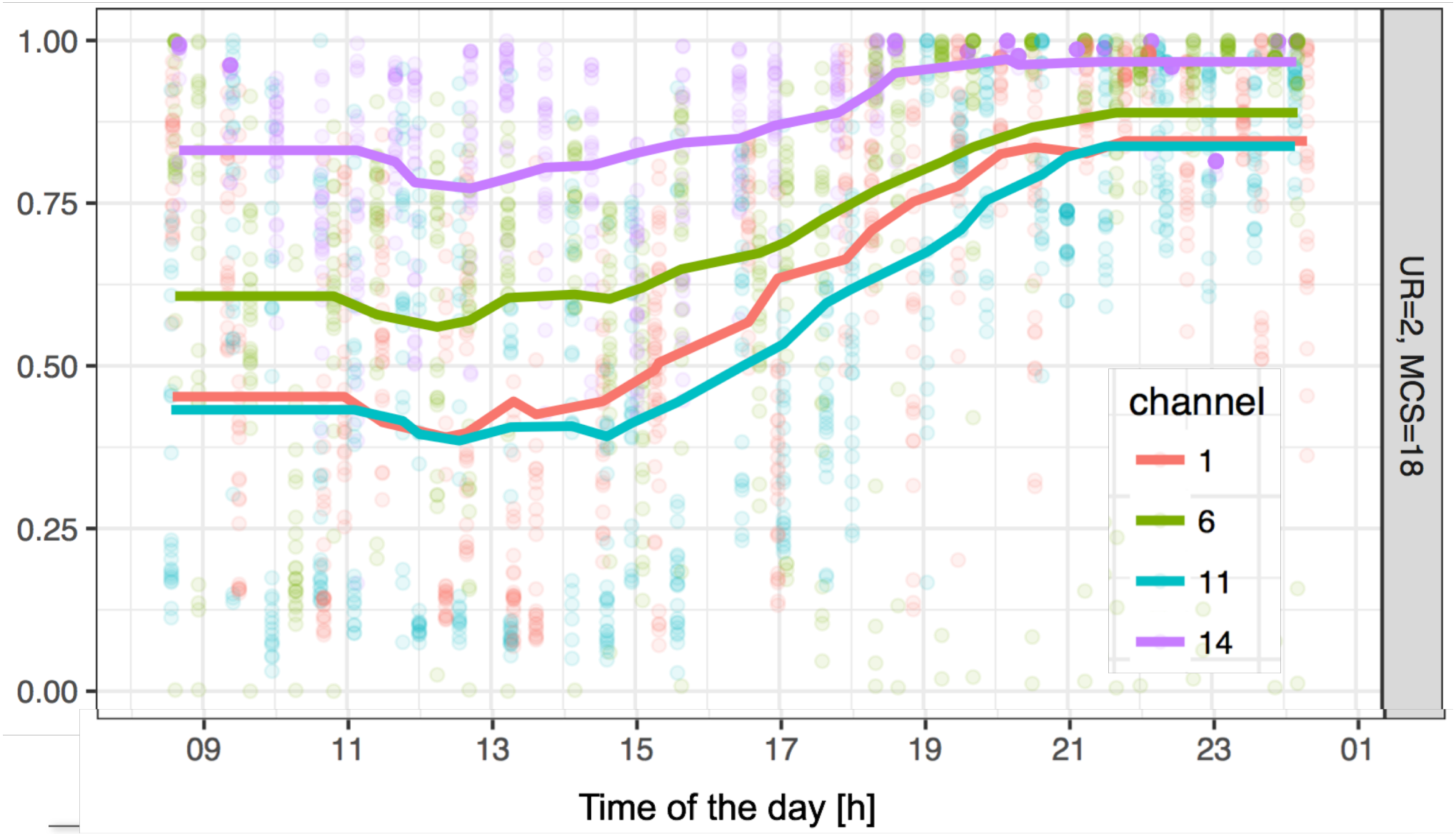
- Chose a video at random
- Chose a channel in round robin
  - Channel = {1, 6, 11, 14}
- Send video, save SSIM
- Repeat during 24 h (working day)

- Figures: SSIM per station (dots), average SSIM (lines)

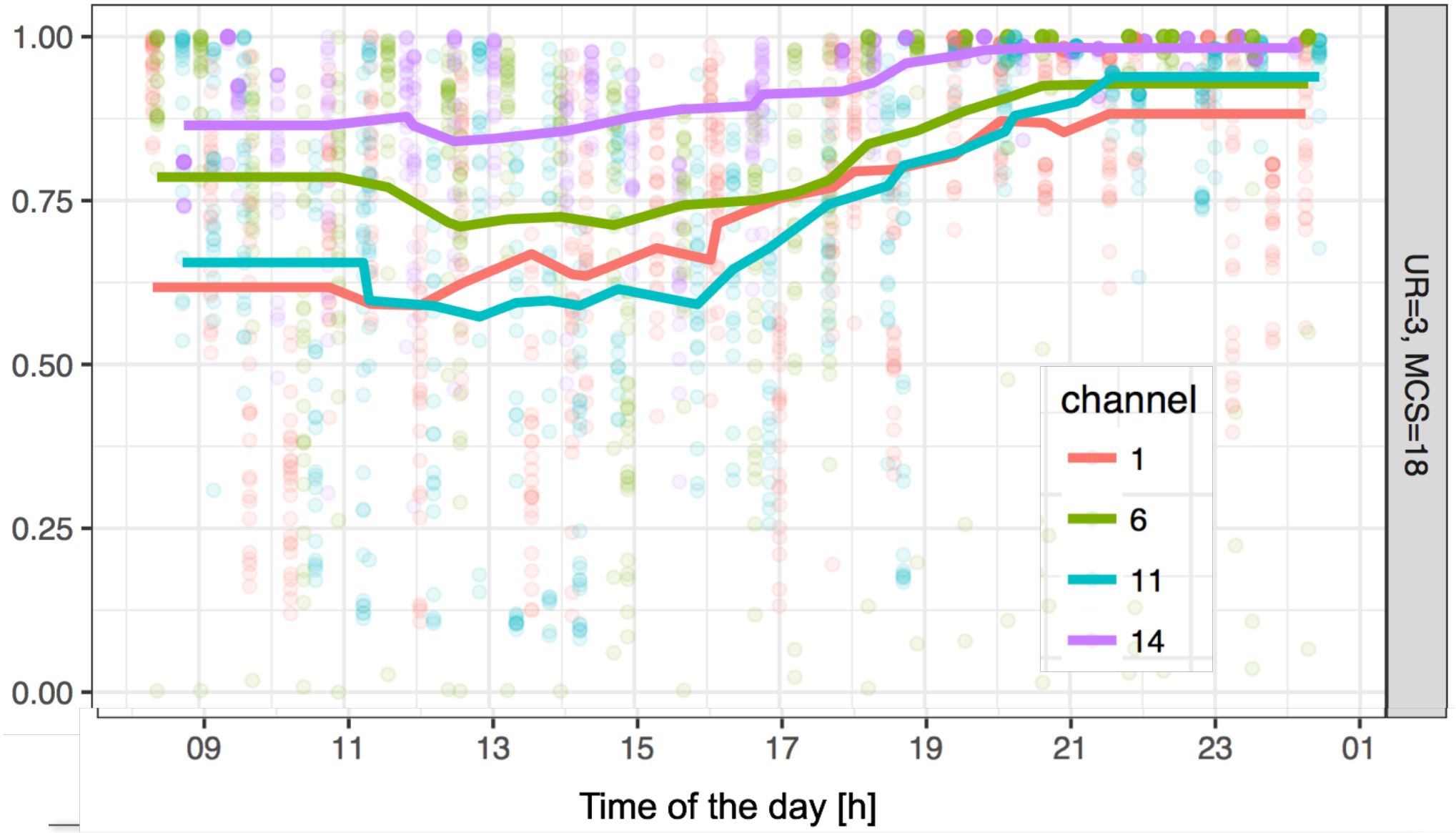
Performance evaluation: legacy



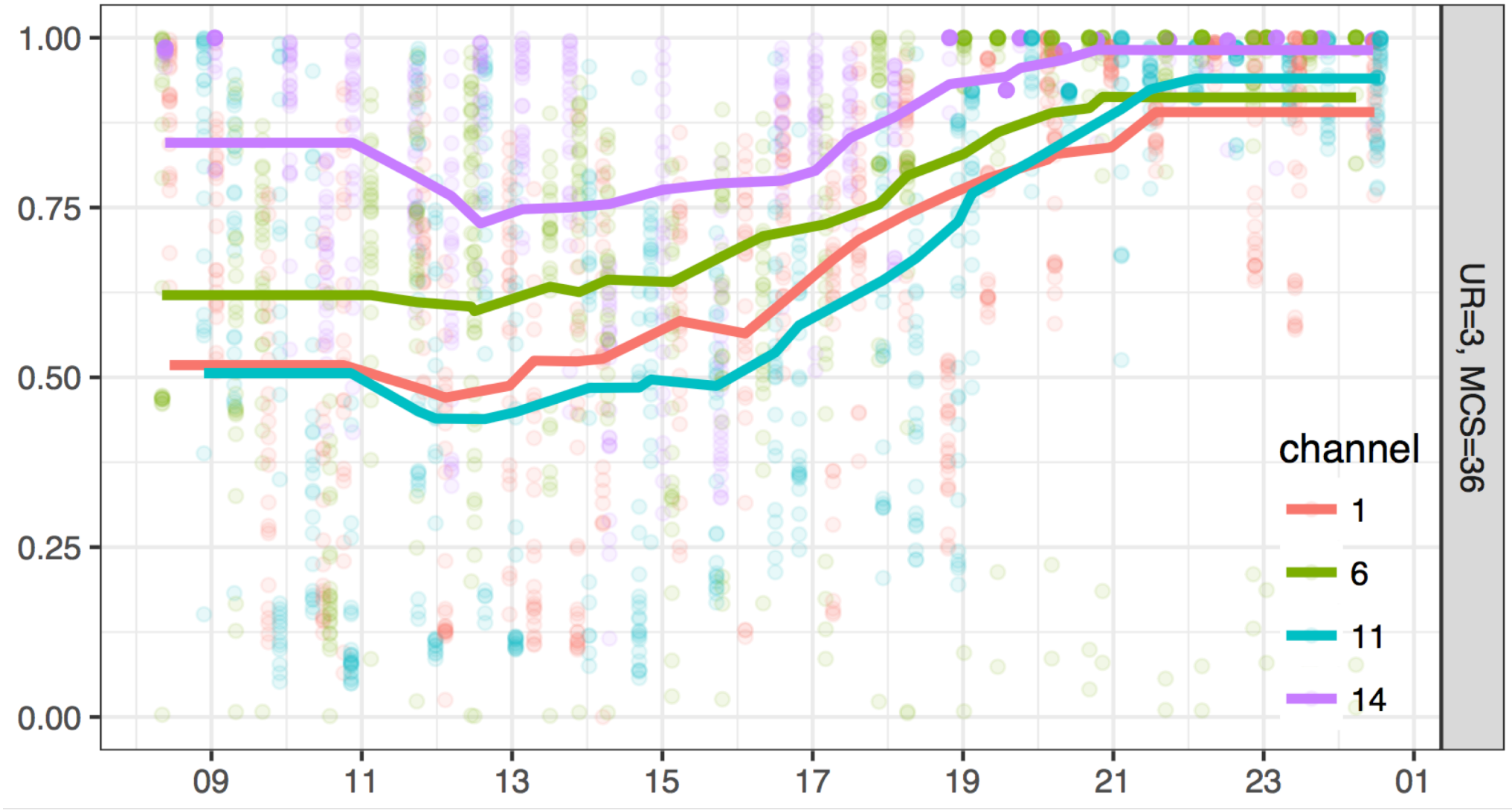
UR=2, 18 Mb/s


1.00
0.75
0.50
0.25
0.00
09
11
13
15
17
19
21
23
01
Time of the day [h]
channel
1
6
11
14
UR=2, MCS=18

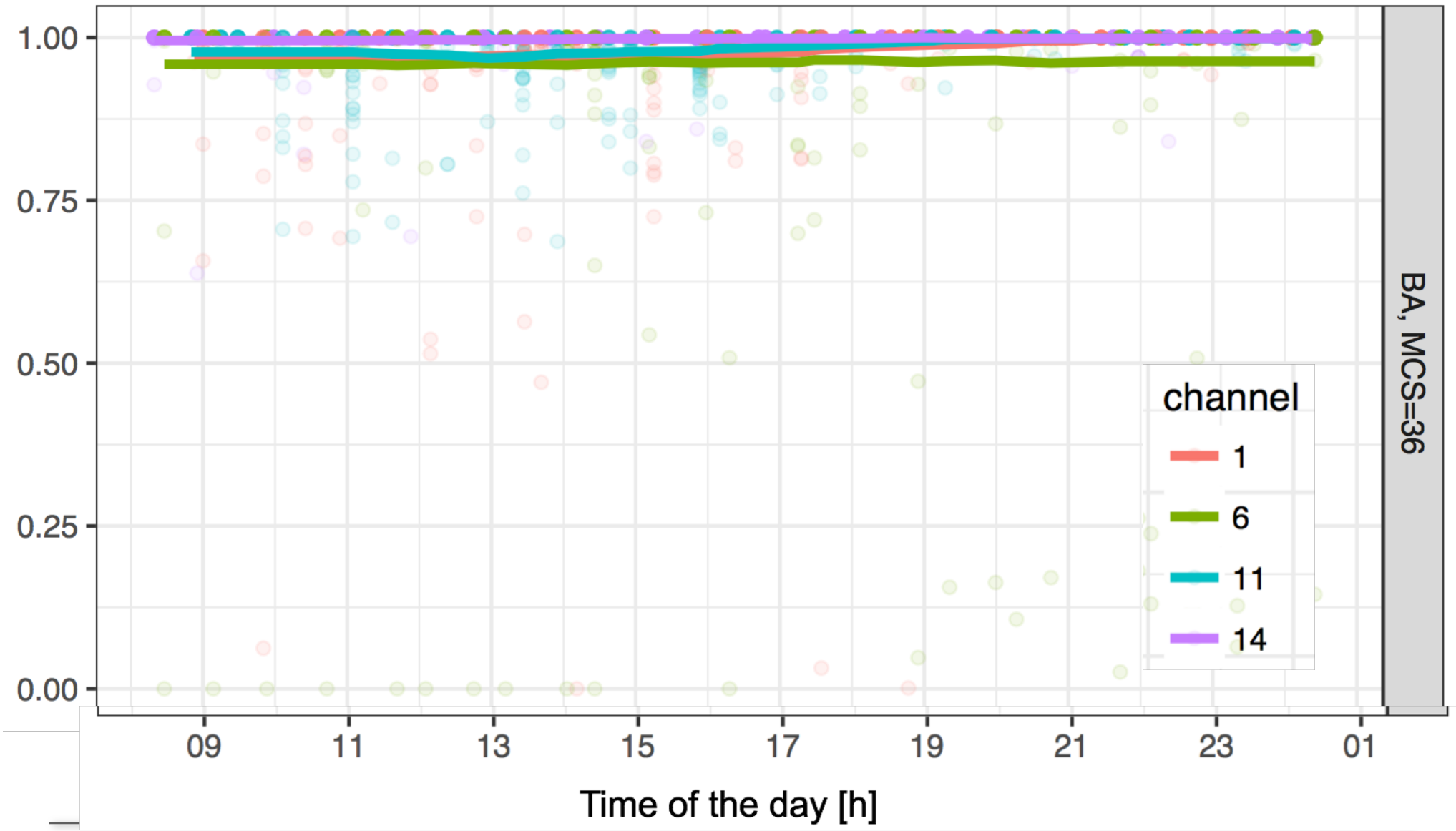
UR=3, 18 Mb/s


1.00
0.75
0.50
0.25
0.00
09
11
13
15
17
19
21
23
01
Time of the day [h]
channel
1
6
11
14
UR=3, MCS=18

UR=3, 36 Mb/s


1.00
0.75
0.50
0.25
0.00
09
11
13
15
17
19
21
23
01
channel
1
6
11
14
UR=3, MCS=36
Time of the day [h]

BA


1.00
0.75
0.50
0.25
0.00
09
11
13
15
17
19
21
23
01
Time of the day [h]
channel
1
6
11
14
BA, MCS=36

Summary & Future work

- UR=2 is OK under no interference
- BA is OK
- EDCA differentiation: little protection

- Future work
  - Massive scenarios
  - Other encodings, H.265
  - Dynamic configuration

Many Thanks!

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Nicolo Facchi, Arturo Azcorra)

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