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Melbourne, Australia

An In-depth Study of Bandwidth Allocation across Media Sources in Video Conferencing

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Video Conferencing Applications (VCAs)

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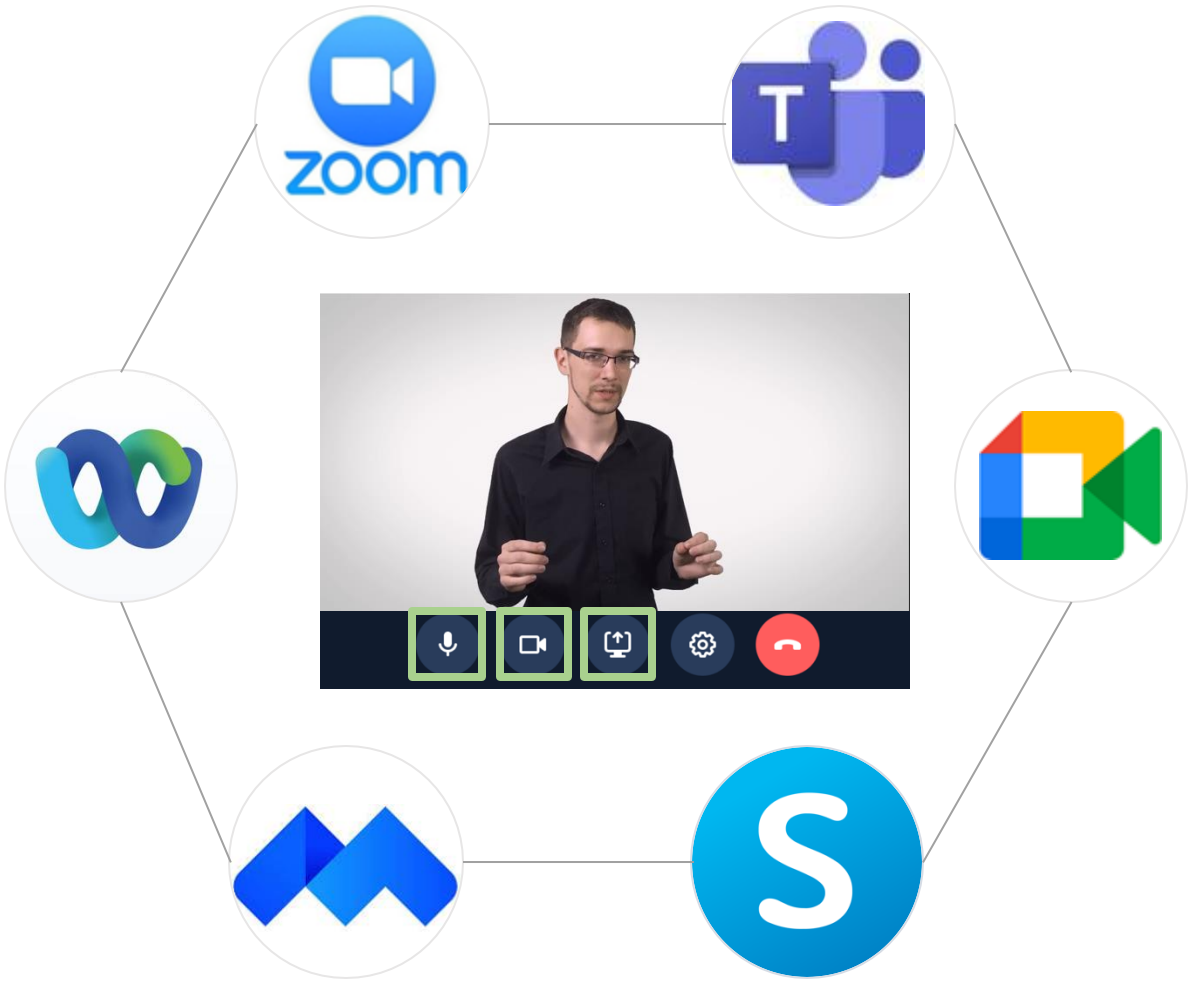

Online Conferences

Online Education

Online Discussion

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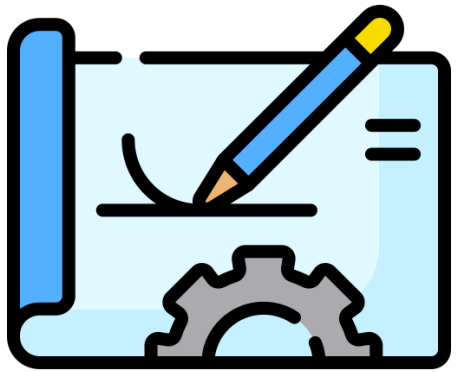
Characterizing VCAs: Existing Work

e.g., Xu *et al*. [IMC'12], Chang *et al*. [IMC'21], MacMillan et al. [IMC'21], Saini *et al*. [JAZ'23], *etc*.



System Design

Quality-of-Experience (QoE)

Network Utilization

- Limited media sources: only audio and/or video stream(s)
- Lack of a quantitative QoE assessment

Characterizing VCAs: Research Problems

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- How do VCAs allocate bandwidth across diverse media sources?
  - When bandwidth is limited
- What are the QoE implications of different bandwidth allocation strategies?
- Can we develop a unified QoE model for modern VCAs?

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Our Contribution

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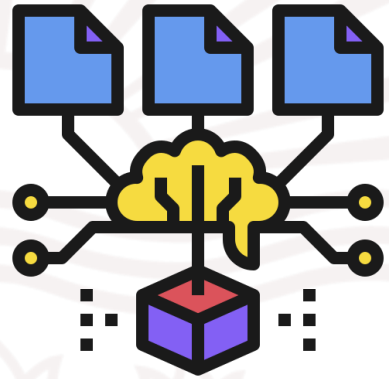
A measurement study

- Media sources: audio, video, screen
- Bandwidth allocation strategy
- Zoom case study

A large-scale user study

- 800 participants & 45,000+ ratings



A generic QoE model

- Across VCAs, scenarios, media sources
- VCAs QoE evaluation

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Challenges

- Commercial VCAs are closed-source
  - How to efficiently acquire QoE metrics, *e.g.*, data rate, resolution, latency, *etc*.
- User study design
  - How to determine a representative subset of bandwidth allocation samples
- QoE modeling across VCAs/scenarios/media sources
  - How to ensure the generalizability and robustness

Understanding Bandwidth Allocation Strategy

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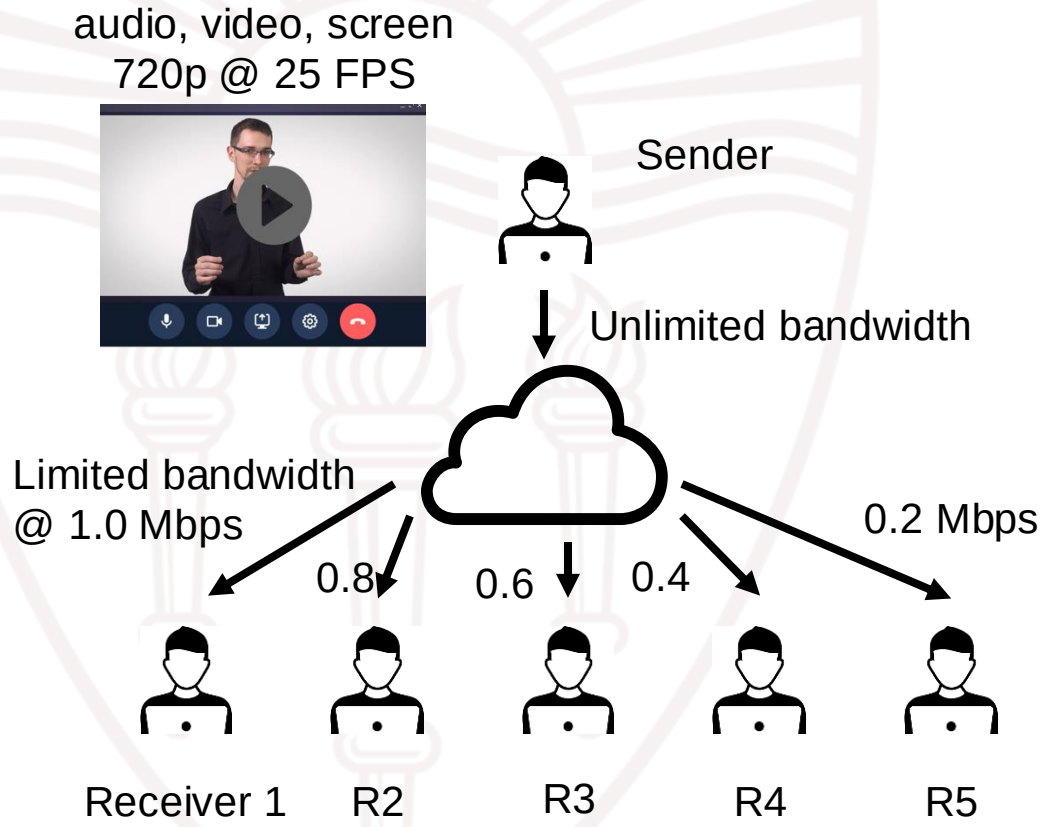
- Methodology
  - 4 {audio, video, screen} combination scenarios
  - 3 VCAs: Zoom, Webex, Google Meet
  - More details are in our paper

	Audio	Video	Screen
Scenario 1	√	(Full-Screen)	
Scenario 2	√		(Full-Screen)
Scenario 3	√	(Thumbnail)	(Full-Screen)
Scenario 4	√	(Half-Screen)	(Half-Screen)



Key takeaway

- 3 VCAs share the same prioritization when allocating bandwidth: audio > video > screen

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Case Study: Zoom

- Video transmission

	Sender (Unlimited)	Receiver1 (Unlimited)	Receiver2 (750Kbps)	Receiver3 (500Kbps)	Receiver4 (250Kbps)	Receiver5 (150Kbps)
Data rate (Kbps)	1158±120	883±130	647±85	453±44	218±35	144±20
Framerate (FPS)	21±3	21±3	13±2	10±2	8±1	7±2
Resolution	360p	360p	360p	360p	180p	144p
SSIM		0.89	0.87	0.84	0.82	0.8
VMAF		91	73	66	41	22

Ensure a better framerate by sacrificing resolution and SSIM ➔ Fluency

- Screen transmission

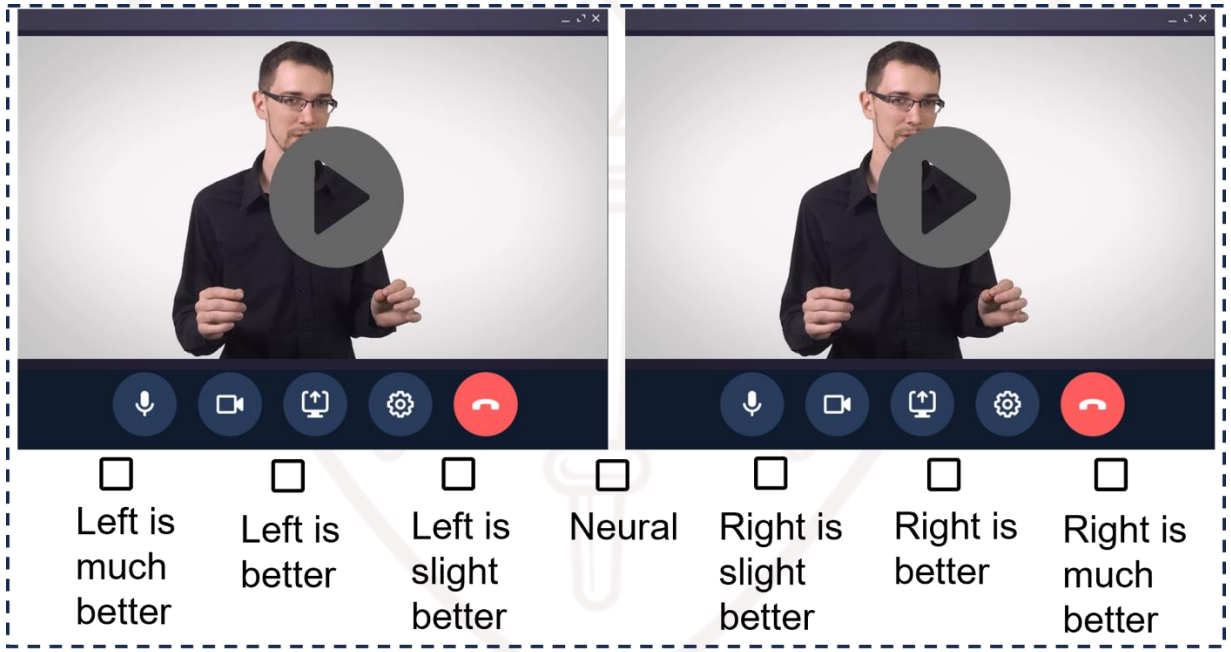
	Sender (Unlimited)	Receiver1 (Unlimited)	Receiver2 (750Kbps)	Receiver3 (500Kbps)	Receiver4 (250Kbps)	Receiver5 (150Kbps)
Data rate (Kbps)	1482±230	1439±230	547±150	326±85	168±40	118±20
Framerate (FPS)	10±2	10±2	4±1	2±1	1±1	<1
Resolution	720p	720p	720p	720p	720p	720p
SSIM		0.91	0.89	0.88	0.87	0.85
VMAF		90	86	82	75	64

Ensure a high resolution by decreasing the framerate ➔ Clarity

QoE Modeling: User Study

- Setup
  - {27, 27, 243, 243} bitrate combination samples
    - For Scenario {1, 2, 3, 4}
  - Each clip > 15s
- 800 participants & 45,000+ ratings
  - Ratings: accumulated score
  - Translate to QoE values: PageRank
- More details are in the paper

	Audio	Video	Screen
Scenario 1	√	(Full-Screen)	
Scenario 2	√		(Full-Screen)
Scenario 3	√	(Thumbnail)	(Full-Screen)
Scenario 4	√	(Half-Screen)	(Half-Screen)



QoE Modeling: Model Design

- General & scenario-specific QoE model
  - Parameters
    - General: Audio + Video + Screen + Bandwidth + Others
    - Scenario 1: Audio + Video + Bandwidth
    - Scenario 2: Audio + Screen + Bandwidth
    - Scenario 3 & 4: Audio + Video + Screen + Bandwidth

Category	Parameter
Audio	[audio bitrate]
Video	[video resolution, video framerate]
Screen	[screen resolution, screen framerate]
Bandwidth	[overall bitrate]
Others	[ratio of window size between video and screen]

Table 7: Input parameters of each media source.

QoE Modeling: Model Evaluation

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- Dataset: from user study
  - Training : Evaluation = 8 : 2
- Investigated ML models
  - Logistic Regression
  - Random Forest Regression (RF)
  - Gradient Boosting Decision Tree (GBDT)
  - Multi-layer Perceptron Regression (MLP)

- MLP has the best performance
- Our QoE modeling is generic across diverse scenarios/media sources

Scenario	Logistic			RF			GBDT			MLP		
	MAE	*RMSE*	*Accuracy*	*MAE*	*RMSE*	*Accuracy*	*MAE*	*RMSE*	*Accuracy*	*MAE*	*RMSE*	*Accuracy*
Scenario 1	0.12	0.92	82.13%	0.12	0.86	81.3%	0.15	0.93	82.1%	0.12	0.83	84.61%
Scenario 2	0.12	0.96	81.90%	0.13	0.87	82.15%	0.16	0.97	82.20%	0.11	0.85	84.55%
Scenario 3	0.15	2.81	78.79%	0.13	2.50	81.12%	0.16	2.87	81.04%	0.13	2.19	84.37%
Scenario 4	0.14	2.92	80.48%	0.11	2.28	82.06%	0.15	2.67	81.49%	0.12	2.24	82.62%
General	0.19	4.06	70.51%	0.09	1.75	81.63%	0.13	2.56	81.79%	0.08	1.78	82.86%

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QoE Evaluation of Zoom, Webex, Google Meet

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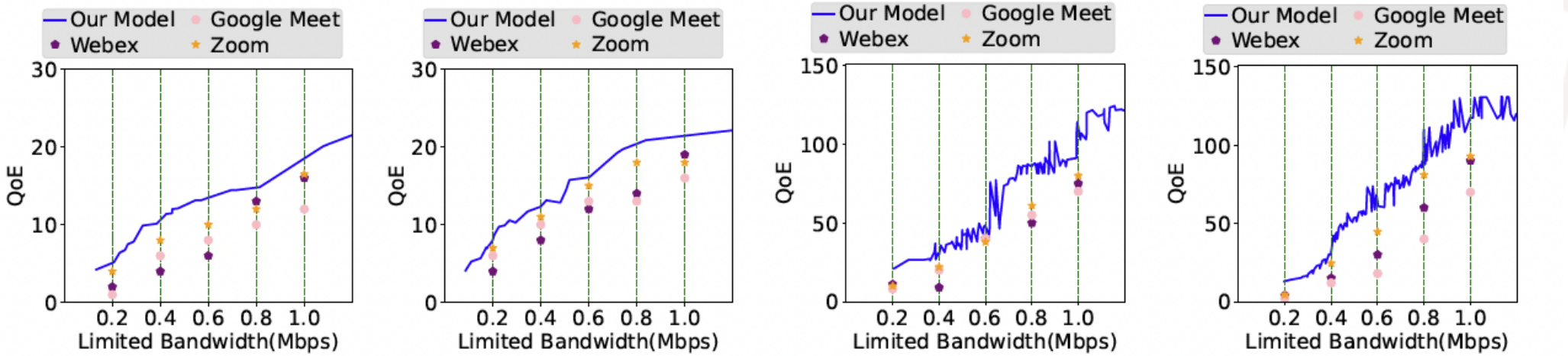
- Setup
  - MLP-based general QoE model
  - Bandwidth: {0.2, 0.4, 0.6, 0.8, 1.0} Mbps
  - Optimal QoE predicted by the model vs. VCA's QoE



(a) Scenario 1 (b) Scenario 2 (c) Scenario 3 (d) Scenario 4

- Zoom consistently achieves higher QoE than Webex and Google Meet in most cases
- None of three VCAs achieve optimal QoE

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Summary

- Limitations of existing VCA measurement studies

- Our work
  - A measurement study of VCAs (Zoom, Webex, Google Meet)
    - Bandwidth allocation strategies across {audio, video, screen}
    - Zoom case study
  - A large-scale user study
    - 800 participants & 45,000+ ratings
  - A generic QoE model for VCAs
    - Across VCAs, scenarios, media sources
    - QoE evaluation of VCAs

- Q & A