EECE5698
Networked XR Systems

Lecture Outline for Today

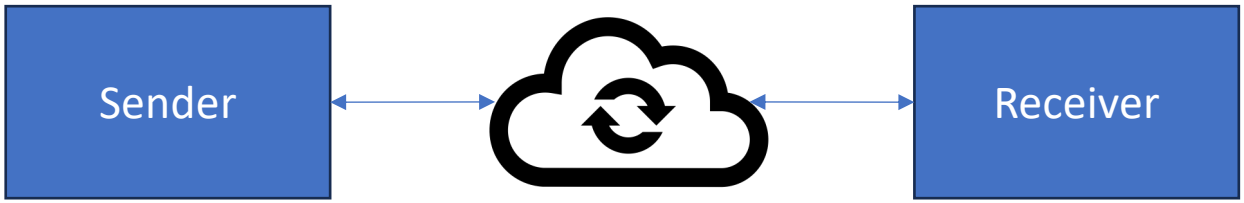
- Homework2 Discussion
- Streaming Fundamentals
- On-demand Video Streaming
- Live Streaming
- Video Conferencing

Homework2

- Most of the parts easy
- Many of you faced difficulty in texture mapping – that's okay – this part is the most difficult part of the homework

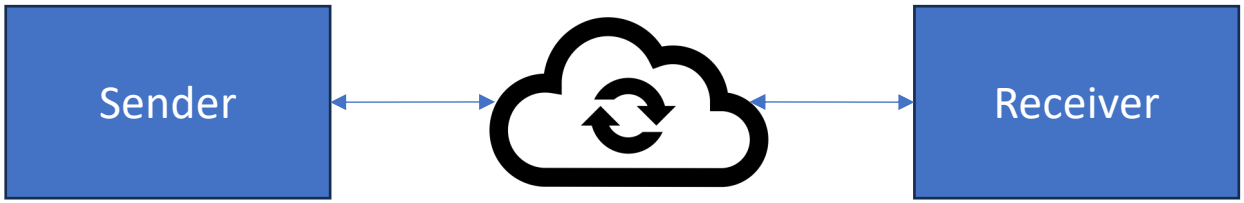
- Open3D does not provide an API for that, you have to write your own function.

Networked XR System



Classical networked system pipeline

Networked XR System



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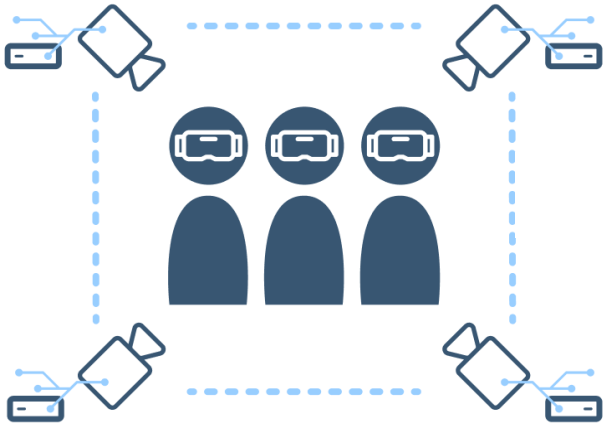
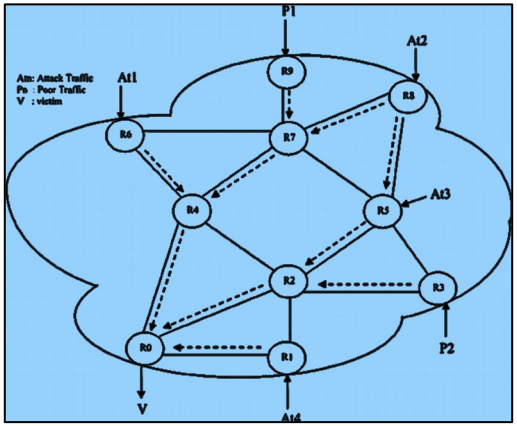
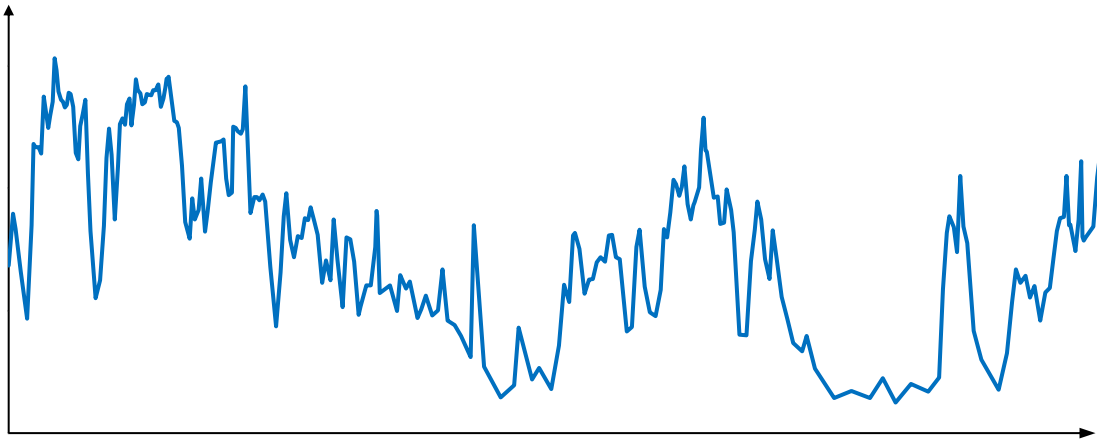




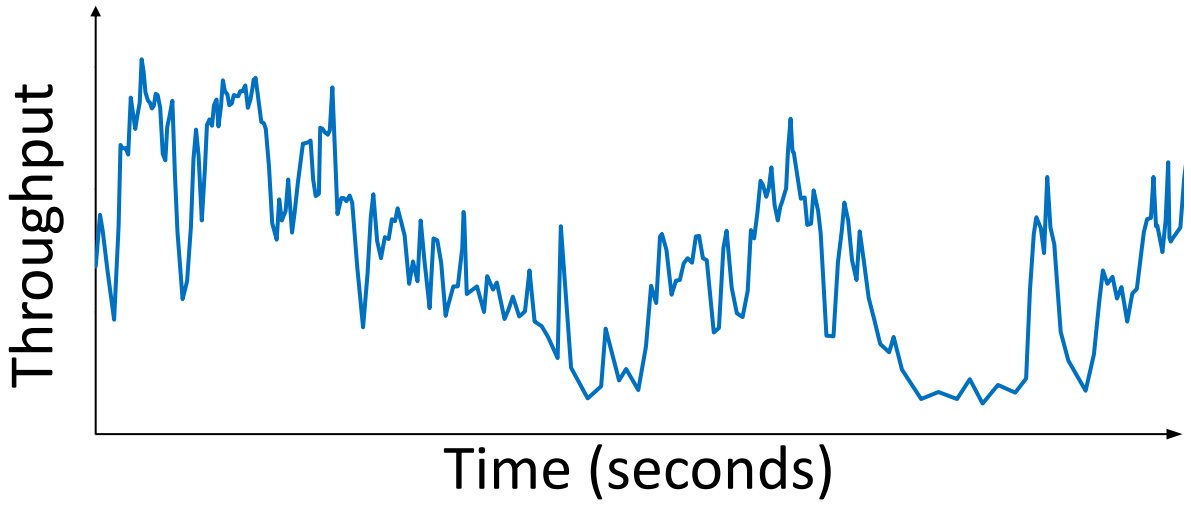
Modern day pipeline

Streaming Fundamentals



What is this graph? And what's going on here?

Streaming Fundamentals



Streaming Fundamentals

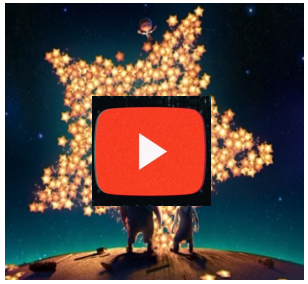
- Bandwidth
  - Wide area, wireless
- Latency
  - Transmission, packet processing, propagation
  - Router bottleneck
- Variability of bandwidth
  - Wide area, wireless
- Synchronization between network and application
  - TCP vs. application traffic control

Streaming Fundamentals

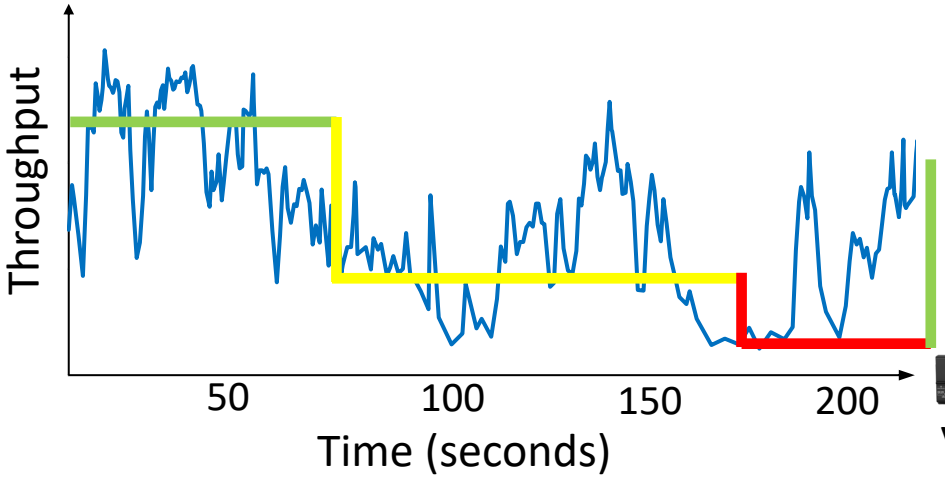
- Solutions
  - Compression
  - Streaming protocol
  - Improve network throughput
  - Tighter integration of apps with network protocols

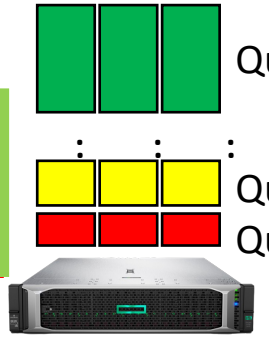
Streaming Fundamentals

- Given these compression principles, what's the best way to compress the content for streaming and/or storage?



Video Client





Video Server

Streaming Fundamentals

- Objective – user quality of experience (QoE)

Surveys

Streaming Fundamentals

- Objective – user quality of experience (QoE)

Models

$$QoE = \alpha + \beta e^{-\gamma \cdot QoS}$$

Fielder et. al, IEEE TON Mar'2010

Streaming Fundamentals

- Objective – user quality of experience

F(QoE Metrics)

$$QoE = \alpha + \beta e^{-\gamma \cdot QoS}$$

Fielder et. al, IEEE TON Mar'2010

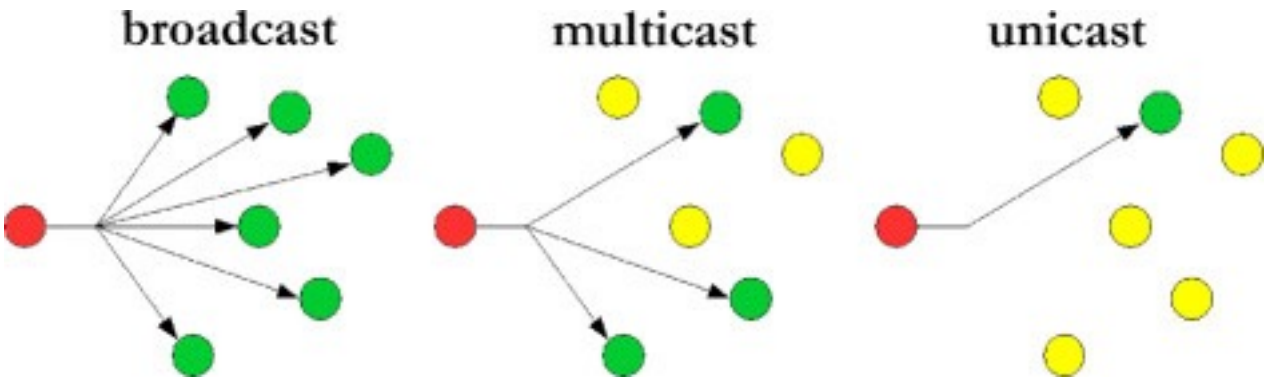
Video on Demand	Video Conferencing	Live	360º Videos	3D
NETFLIX, YouTube	Skype, Zoom	Twitch	360° VIDEOS	
Video quality Stalls Quality changes	Video quality Latency Frame rate	Quality Frame rate	Quality Stalls M-P latency	Quality Stalls M-P latency Geometry

Streaming Fundamentals

- Overall Streaming Pipeline
  - Get the video content and compress it
  - Identify the constraints (e.g., Network)
  - Define objective (user QoE)
  - Make download decisions based on the constraints maximizing the objective

Streaming Fundamentals

- Unicast
  - To one user
- Multi-cast
  - To a group of selected users
- Broadcast
  - To anyone



On-Demand Streaming

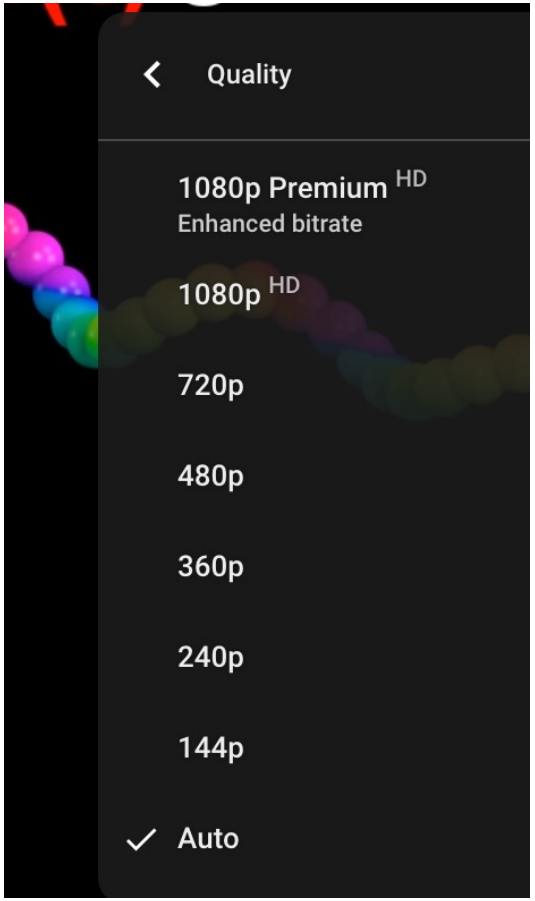
- Users can stream videos any time they want
- Opportunity to cache or pre-fetch when network conditions are good

On-Demand Streaming

YouTube

NETFLIX

TikTok

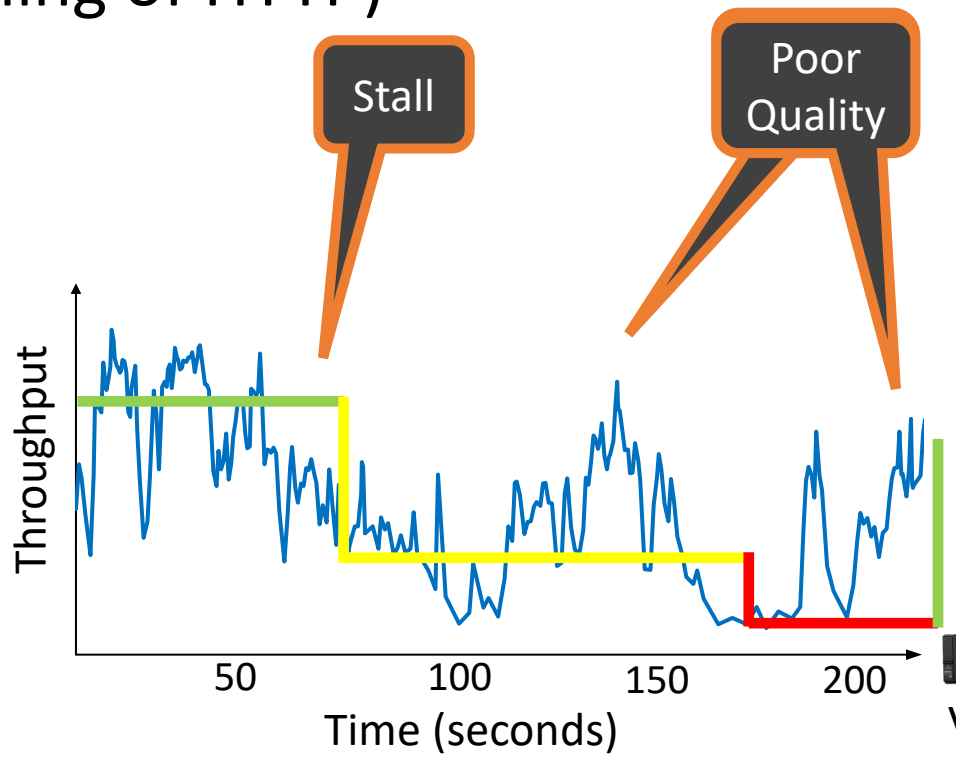


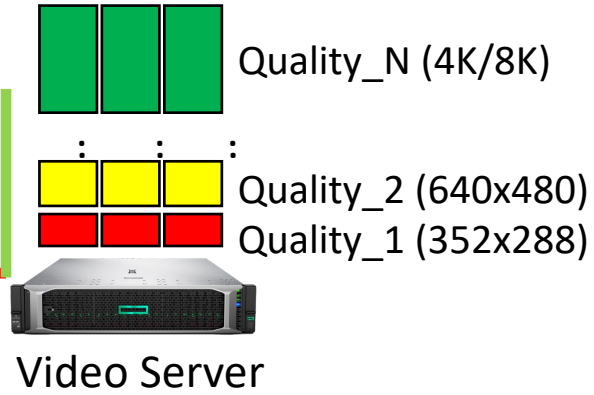
Media is stored in different resolutions at the server

On-Demand Streaming

- Adaptive streaming – DASH (dynamic adaptive streaming of HTTP)

Video Client





On-Demand Streaming

- Quality of experience metrics
- Startup latency
  - Should load the video as quickly as possible
- Re-buffering
  - Buffer should not be empty for playback
- Visual quality
  - More quality the better
- Fluctuations in visual quality
  - Shouldn’t change quality too frequently

On-Demand Streaming

- Need to support different user actions
  - Pause
  - Forward
  - Rewind
  - Skip or jump to a certain part of the video
- Need to re-buffer all over again

On-Demand Streaming

- Storage costs
  - E.g., Netflix stores thousands of different versions <resolutions, file formats, bitrates, …> for each video
  - Can quickly explode storage costs

Live Streaming

- Live (non interactive)
  - Need to support a variety of devices
  - Can afford some delay but not much

Live Streaming

- Important factors
  - Scale – how many users does the server support?
    - Transcode the video to multiple servers & distribute
  - How long the stream will be?
  - What kind of scenario?
    - Live streaming from a phone?
    - Live streaming at a concert or game?
    - Remote assistance application?

Live Streaming

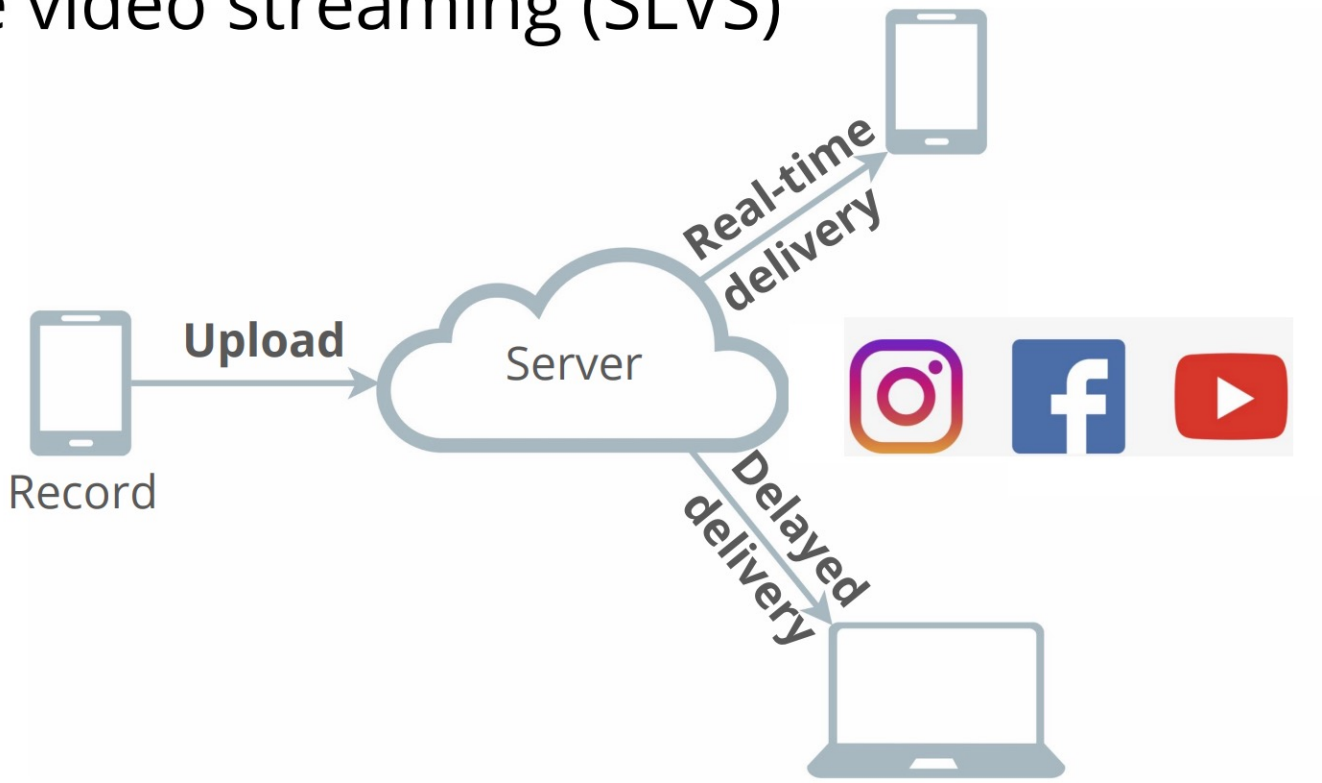
- Recent super bowl live streaming latency numbers

How much can you tolerate?

Source: Phoenix

Live Streaming

Social live video streaming (SLVS)

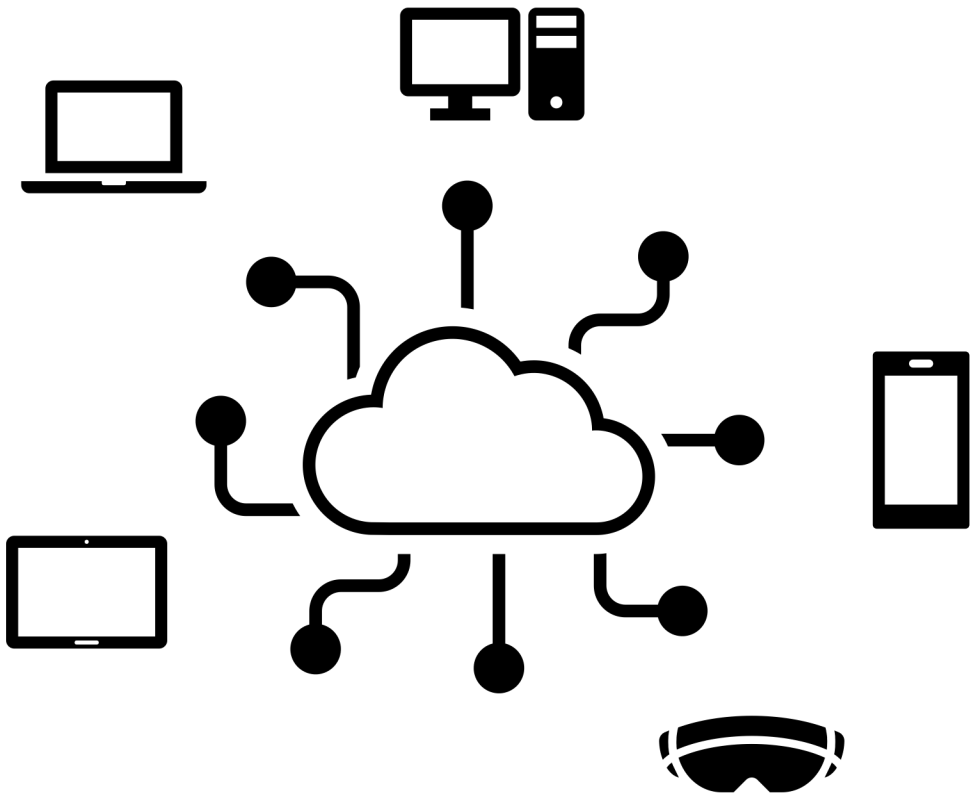


Devedeep et,al: Sigcomm'19

Conferencing

- Interactive
  - Need to support a variety of devices
  - Low latency

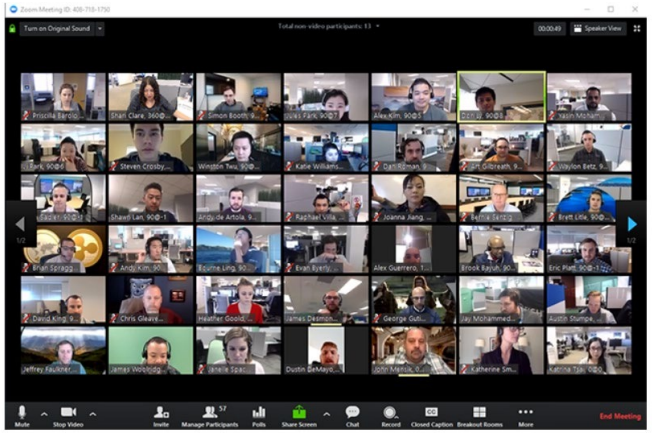
Conferencing



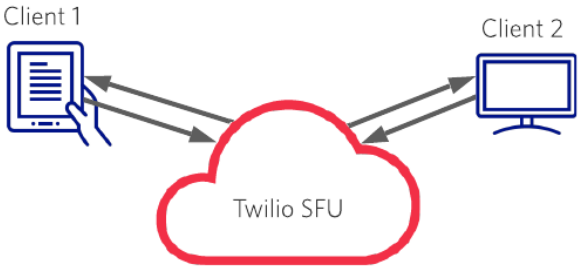
1. Peer to peer systems
2. Server relay
   Transcodes input bitstreams into different versions live and sends them to clients based on their network conditions

Conferencing

- Fewer clients – p2p is okay
- Server based is efficient for large number of clients



Client 1 communicates directly with Client 2



Client 1 communicates directly with the Twilio Selective Forwarding Unit (SFU)

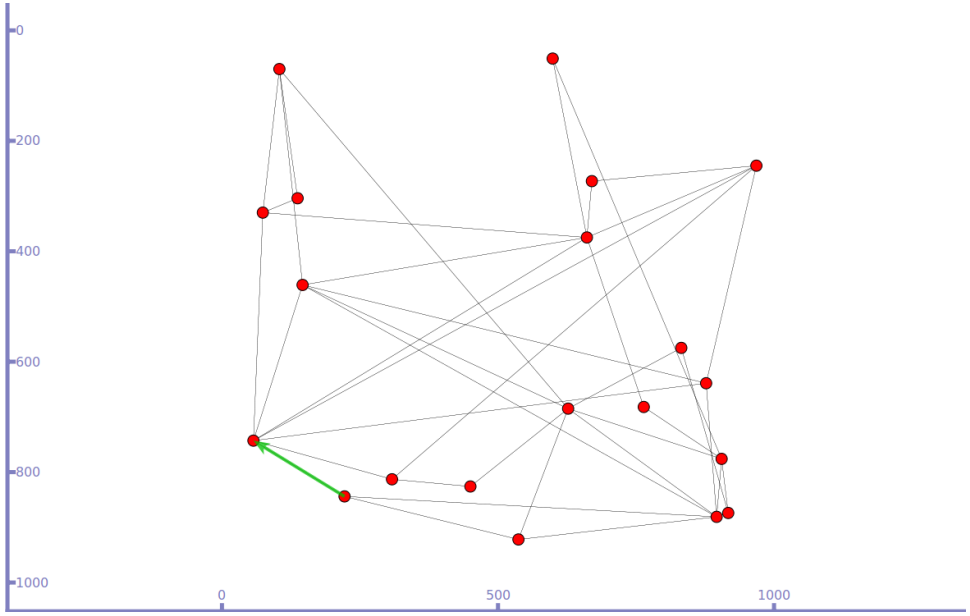
Conferencing

- Metrics
  - Latency (e.g., Zoom or Facetime applications have 100s of ms latency)
  - High frame rate, no freezes
  - High quality
- No option for pause, rewind, or jumping to a different parts of the video

Building and Testing Streaming Protocols

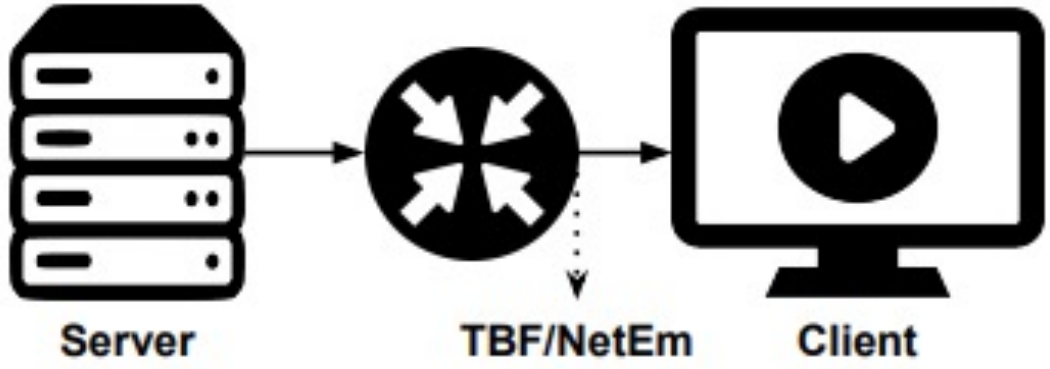
- Simulation
  - Model traffic
  - Model network
  - Model compression
  - Build protocol
  - Test and evaluate

ns-3 NETWORK SIMULATOR



Building and Testing Streaming Protocols

- Emulation – slightly more realistic



Stream videos over realistic network conditions
Record & Replay real world network traces

Summary of the Lecture

- Streaming fundamentals
- On-demand video streaming
- Live streaming
- Video conferencing
- Building and testing streaming protocols

Next up: Adaptive Bitrate Algorithms