EECE 5512: Networked XR Systems | Fall'25

Prof. Dasari

mallesham.com

Spatial Intelligence Research Group

sinrg.org

LVX VERITAS VIRTVS

Northeastern University

Lecture Outline for Today

- Logistics
  - Quiz (not for grading)
  - Schedule, Instructor info
  - Grading, Communication, Expectations
- Introduction to XR
- Basics of Networked XR systems

Short Anonymous Quiz (Not for grading)

- https://forms.gle/V7HzSPeJwgS1cM4o9

Schedule and Instructor Info

Instructor: Mallesham Dasari
Office: 650D EXP Building

Class Times: MoWed 2:50PM-4:30PM
Class Room: Room 256, Richards Hall
Office Hours: MoWed 4:30PM-5:30PM; also on Appointment or open doors
Contact: m.dasari@northeastern.edu

Course Webpage: https://mallesham.com/courses/eece5512/fall25/index.html

Grading

Quiz: 10%
Homeworks: 40%
Project: 50% (plus bonus of up to 10% if the project outcome is beyond expectation)

All deadlines are due 5pm unless otherwise specified

Late Days

- Quizzes - 5
  - No late days
- Homework - 4
  - 4 late days in total across all of them
- Project - 1
  - Demo and a presentation
  - Last day of class or exam week

Homework and Project

- Most homework will be programming
- No restrictions on language – C/C++, Python, C#, JavaScript, Java, etc.
- Individual (or max 2 team) project
- Project type
  - Implement a research paper that is already been published
  - Conduct a measurement study - experimental
  - Research project

Experience Sessions

- Exploring XR tools
  - Headsets
  - Apps
  - Software
  - Demos of research prototypes
  - Exploring 3D, immersive, spatial content

Experience Sessions

Communication and Support

- Slack
- Canvas
- Piazza?

University Statements

- Student Accommodations
  - Disability services
- Academic Integrity
  - You are allowed to use AI or any tools that you may need help for homework and projects (with a caution – AI can generate garbage sometimes, so it is your responsibility to make sure you're not blindly following what AI is telling you to do)
  - Acknowledge sources

This Class is About

- Building Networked Immersive Experiences
  - Hardware – XR Headsets, Glasses, Sensors, Devices
  - Software - 3D Development tools, Programming Languages.
  - Algorithms – 3D reconstruction, compression, network protocols, streaming methods.

This Class is Not About

- Computer Graphics
  - 3D Modeling, Rendering, Geometry Manipulation
- Computer Vision
  - SLAM, Image Feature Extraction, Face Recognition, Classification, Segmentation, Object Detection, etc.
- Computer Networks
  - Wireless, Cellular, Wide Area Internet Protocols
  - Routing, Congestion Control
  - Physical Layer, MAC Layer

Tentative Topics

This is an interdisciplinary course covering the following topics from emerging multimedia, computer networks, vision and graphics. In addition to the regular lectures, the class will also have experiential sessions with a vareity of state-of-the-art XR headsets in the market.

- Fundamental problems of networked applications
- XR content representations
- 2D, Flat 360, 3D/Volumetric videos (RGB-D, point cloud, mesh, NeRF)
- Monocular, stereoscopic, and multiview videos
- Acquiring XR content for network delivery
- Compression algorithms for RGB and depth videos
- Compression algorithms for point cloud and mesh sequences
- Multiview compression algorithms
- Streaming fundamentals
- Stored, live, and interactive streaming protocols
- Streaming XR content (videos, point clouds, meshes, holograms, spaces)
- Content delivery networks
- Local streaming via WiFi, mmWave and optical wireless links
- Remote and hybrid rendering
- Visual and wireless sensing for person tracking
- Networked XR platforms such as ARKit/Core, Unity, Open3D
- Building XR systems such as 3D telepresence (VR), Spatial Web (AR)

Tentative Schedule

Subject to minor tweaks throughout the semester.

Date	Topics	Lecture slides & Readings	Notes
09/04	Introduction, networked applications, properties, basics of XR systems.		
09/09	XR headsets, internals, hardware, software, and tools.		Homework1 out. Due 09/22.
09/11	Sensors, cameras, depth sensors, lidars, sensing, algorithms.		
09/16	3D data structures, point clouds, depth maps, geometric meshes, neural representations, mono, stereo, and multiview.		
09/18	Capturing 3D data for network transmission, outside-in and inside-out capture, latency and bandwidth trade-offs.		
09/23	Compression fundamentals, 2D video compression.		
09/25	Depth map compression, adopting 2D video codecs, standalone depth compression.		Homework2 out. Due 10/08.
09/30	Point cloud compression, MPEG VPCC, GPCC.		
10/02	Geometric mesh compression, Draco, Inter-frame mesh compression.		Project idea due.
10/07	Machine learning advances in XR content.		

Tentative Schedule

10/09	Machine learning advances in XR content compression.		
10/14	No class		
10/16	Streaming fundamentals, on-demand, conference calls, live broadcasting.		Homework3 out. Due 10/29.
10/21	2D video streaming, adaptive bitrate algorithms.		
10/23	360-degree video streaming.		
10/28	Point cloud streaming, point cloud quality metrics, adaptive algorithms.		Project midterm evaluation 1.
10/30	Mesh streaming, decimation, mesh quality metrics, adaptive algorithms.		
11/04	Progressive transmission of XR content.		
11/06	XR Experiences Session		Homework4 out. Due 11/19.

Tentative Schedule

11/11	No class		
11/13	Class in and about Metaverse.		
11/18	Rendering basics, Real time rendering, Performance, Rendering offloading.		
11/20	Edge rendering, local streaming, WiFi, mmWave, THz, optical links, challenges and opportunities.		Project midterm evaluation 2.
11/25	Hybrid rendering, optimal scheduling, WebRTC.		
11/27	No class		
12/02	Tracking Fundamentals: Eye tracking, head tracking, outside-in, inside-out tracking		
12/04	Tracking Fundamentals: Hand tracking, full body tracking, face tracking		
12/13	**Final project submission.**		

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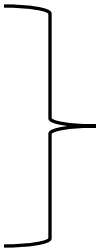
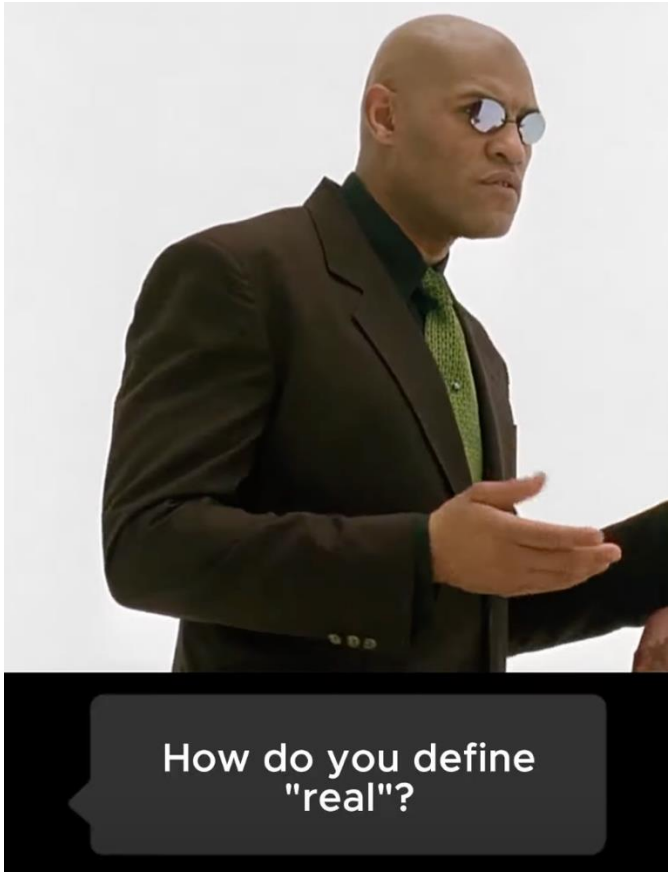


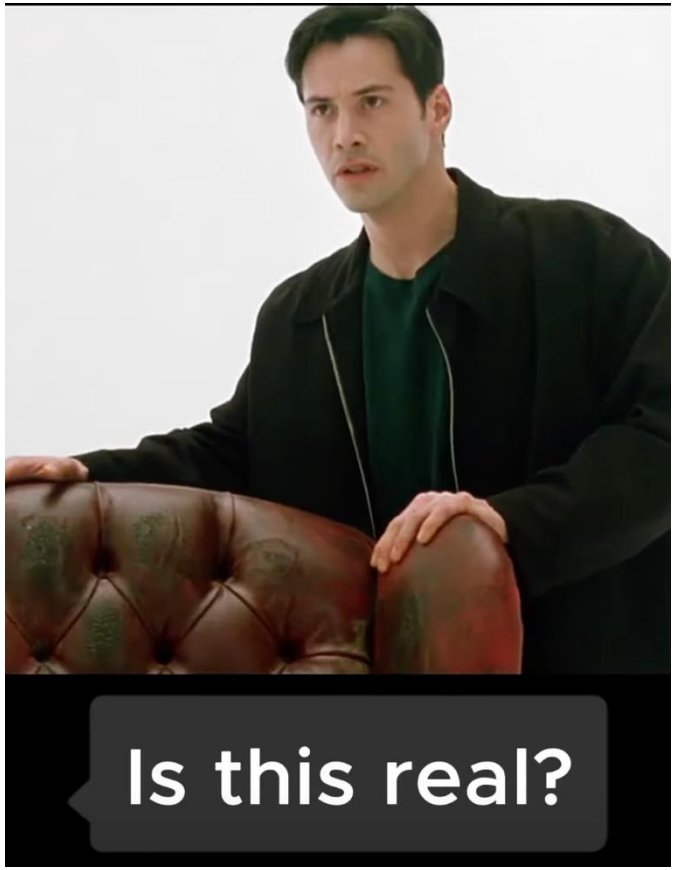
Any Questions?

What is XR (Extended Reality)?

- A catch-all phrase for AR, VR, MR…
- Textbook definition: Bring digital world to our physical world

What is XR (Extended Reality)?





”real” is simply electrical signals interpreted by your brain

Augmented Reality

- Overlays digital content in the physical world

Augmented Reality

- Variety of platforms
  - Smartphones, Headsets, Glasses
- Requires continuous tracking
  - Hands, Body, Person
- Display methods
  - Video see-through
  - Optical see-through

Mixed Reality

- Same as Augmented Reality
- Microsoft tried to rebrand it for marketing
  - Interaction highlighted

Virtual Reality

- Completely immersed in digital world

Virtual Reality

- Platforms
  - Only HMDs or VR Glasses; Near-eye Displays
- Motion tracking
  - Head, Eyes, Face, Body, Hands, Gestures, etc
- Other than visual sensors
  - Sound, Tactile Feedback for touch

AR vs. MR vs. VR vs. XR

- AR = Virtual + Physical
- MR = AR (or interactive AR)
- VR = Purely Virtual
- XR = A catch all term for all of the above

- Metaverse – Meta
- Spatial Computing – Apple

- Immersive Computing - Academia

- Digital Twins

XR Hardware

Sensors
Display
Compute Pack

https://www.ifixit.com/Teardown/Magic+Leap+One+Teardown/112245

XR Software

- Rendering Engines
  - Unity, Unreal
  - WebGL
- 3D modeling tools
  - Blender
  - Maya
- User Interfaces
- Programmable 3D Manipulation Frameworks
  - Open3D

XR Algorithms

- Sensing and Tracking
  - Eyes, Face, Hands, Head, Body...
- 3D Reconstruction
  - Efficiently extract 3D geometry from raw sensor data
  - From depth data or point cloud data form Lidars
- Real-time rendering algorithms
  - Decimation

Leading Companies of XR

Many startups…

XR Applications - Gaming

Indoor games too

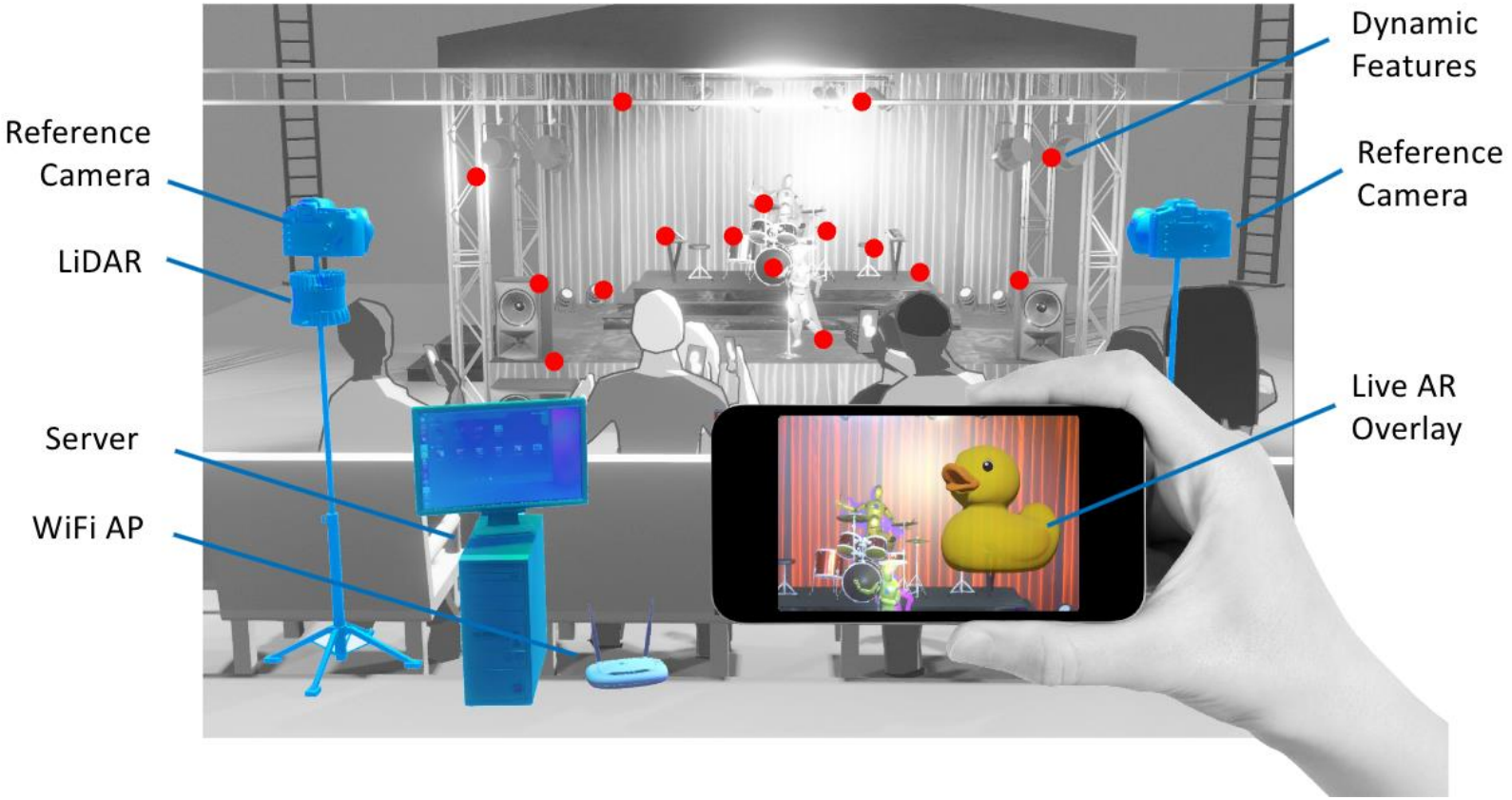
XR Applications – Remote Assist

Hands free Facetime

XR Applications - Medical

Visualize 3D data in thin air

XR Applications - Entertainment



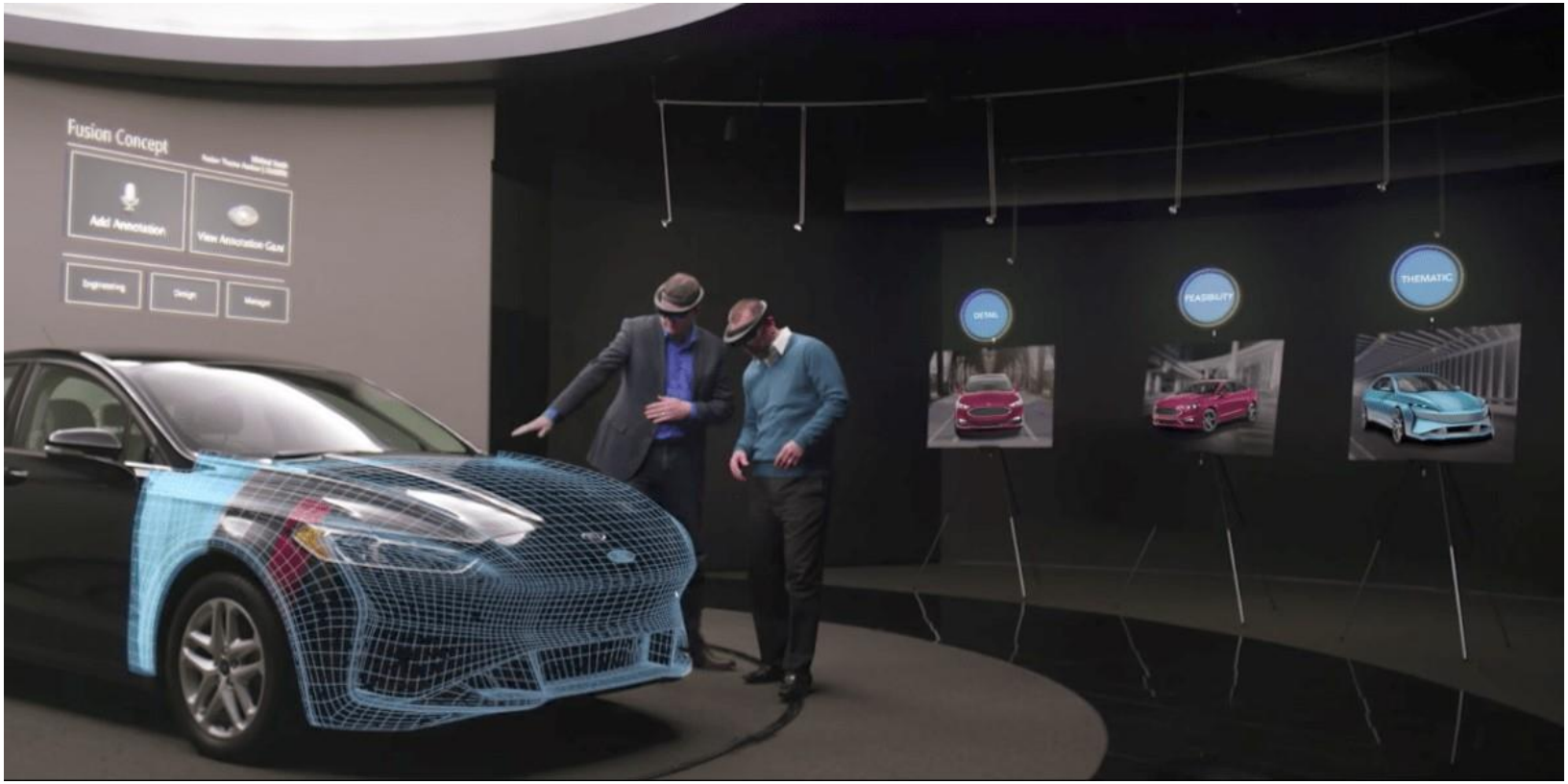
Theater performances

XR Applications - Engineering

XR Applications – Telepresence

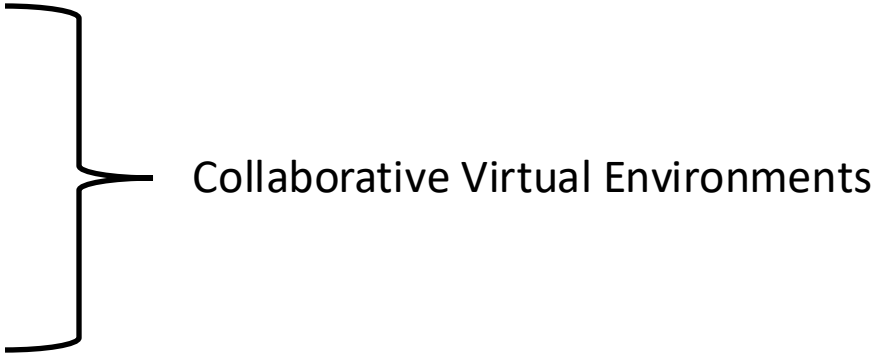
Previously: Large displays, Telepresence robots, etc..

XR Applications - Automotive



XR Systems in Use Today

- Horizon Worlds – Meta
- VRChat
- Mozilla Hubs
- AltspaceVR – dead
- Many Games
- Retail, housing markets have started using 3D models of objects and houses for showing in VR



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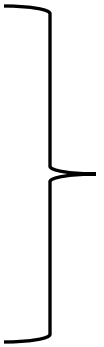


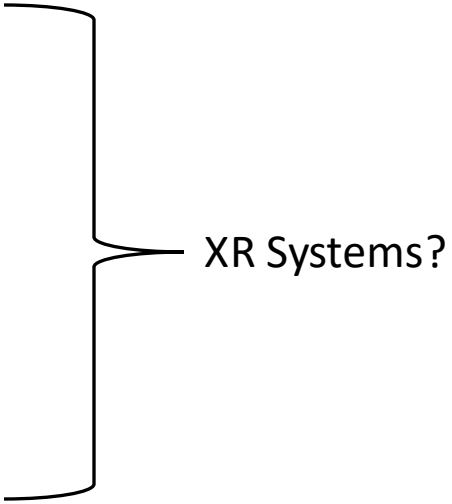
Any Questions?

The Need for Network

- Long Distance Communication
- Accessing Remotely Stored Content
- Accessing Distributed Resources

Networked Systems

- Voice and Video Calls
  - Facetime, Zoom, Teams
- Streaming Content On-demand
  - YouTube, Netflix, Tiktok
- Cloud compute and storage

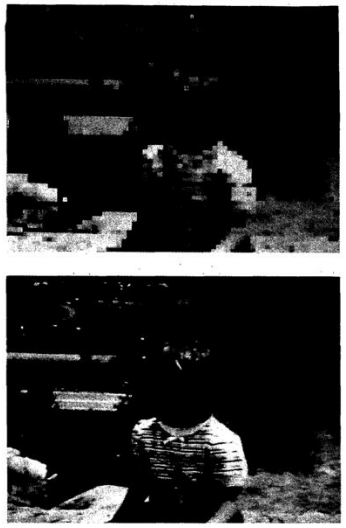


- Printers, and other smart devices communication

A Brief History of Networked XR Systems – 1970 & 1980

- Early attempts of content delivery over the Internet

The Internet



Progressive Image Transmission

Teleconference [64Kbps]

Video on Demand: A Wideband Service or Myth?

C. Judice, E. Addeo, +1 author H. Lemberg Published in ICC 1986 Business

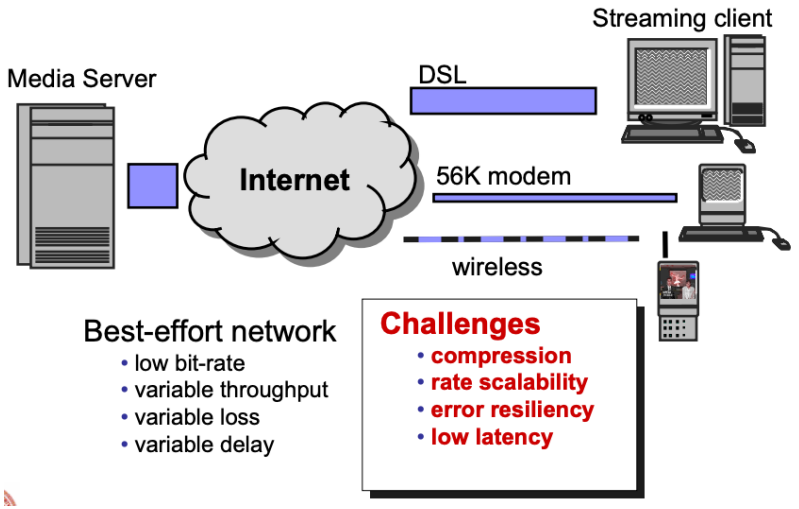
A Brief History of Networked XR Systems – 1990 & 2000

VIDEO ON DEMAND: IS IT FEASIBLE?

W. D. Sincoskie

Globecom'1990

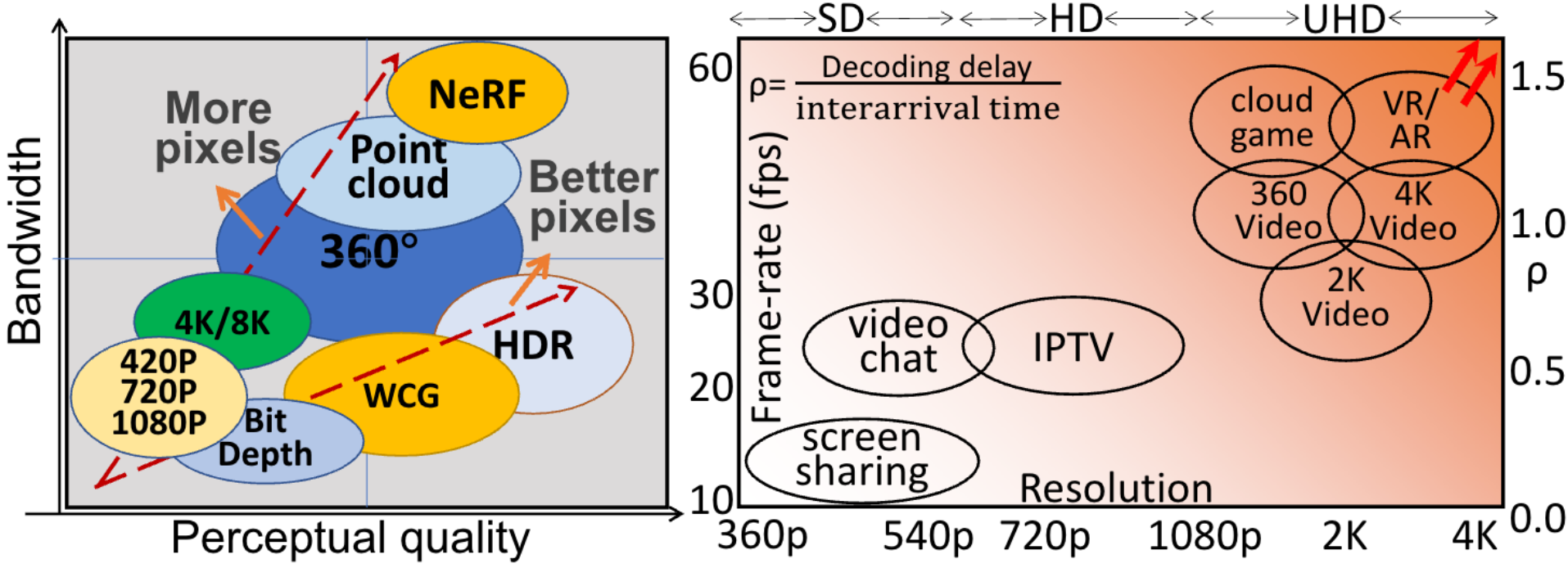
Bell Communications Research
445 South Street
Morristown, NJ 07960-1910



- Early attempts in on-demand video delivery
  - Powerful compute, storage, hardware capacity
  - Video compression (MPEG-1)
  - Internets
  - Progressive Downloads

https://www.youtube.com/watch?v=OV3legWSi6U

A Brief History of Networked XR Systems – 2010 & 2020

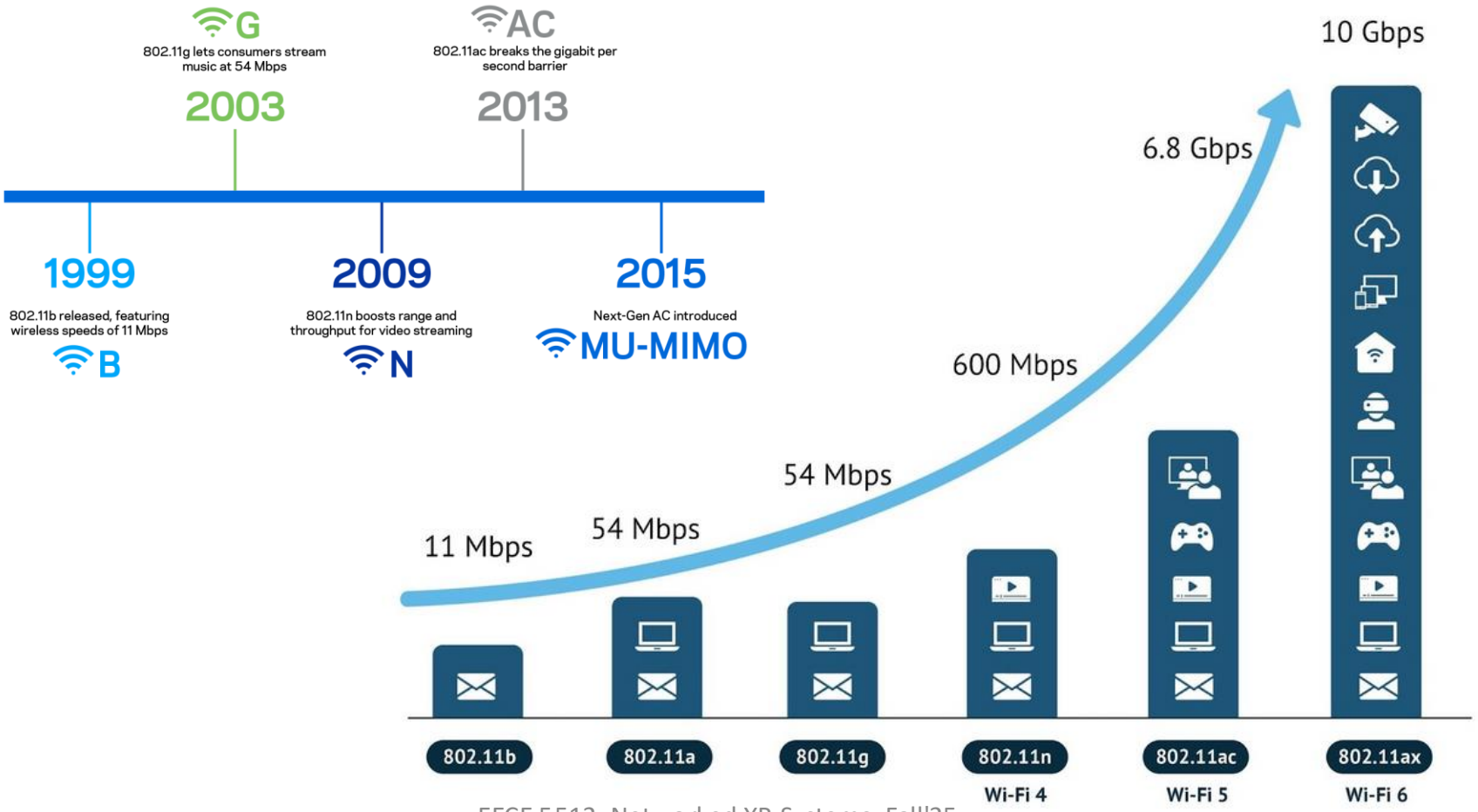


Despite the advances in computer networks, they are still a bottleneck

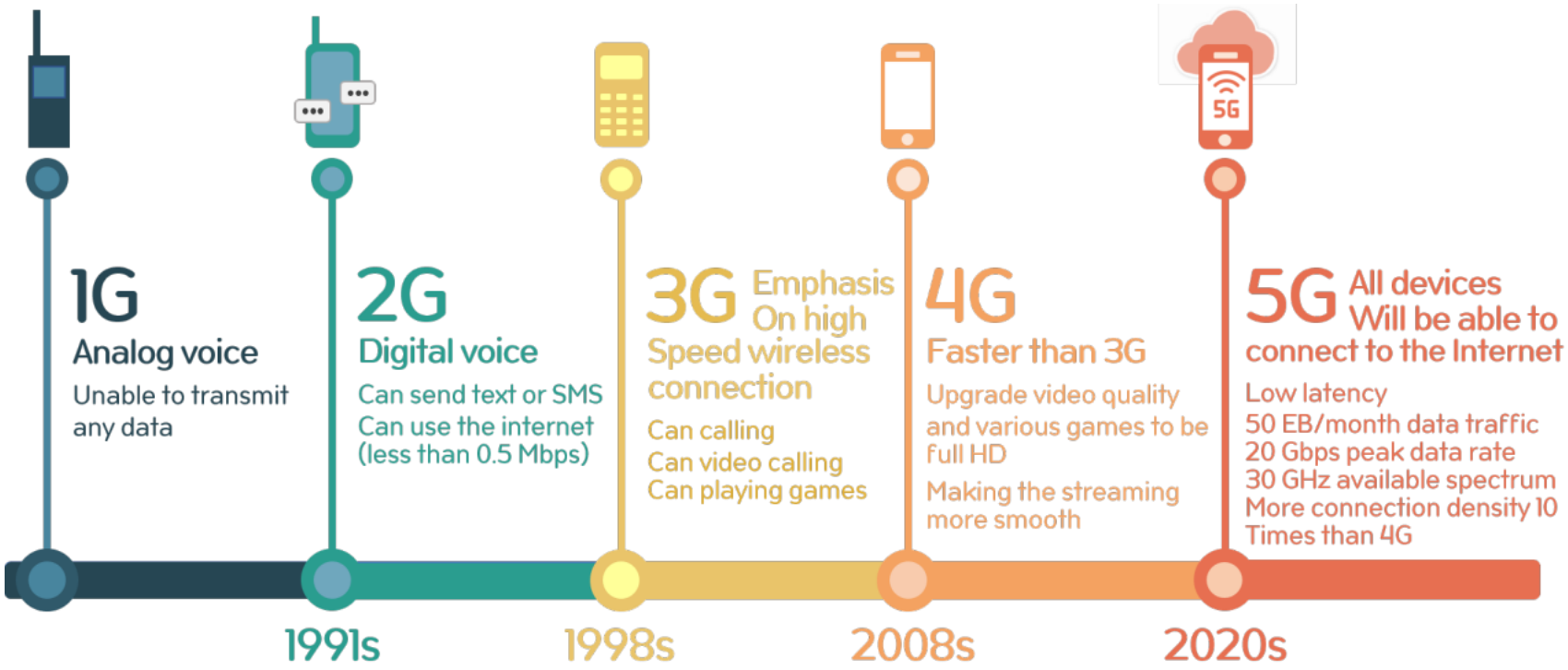
Fundamental Problems of Networked XR Systems

- Network bandwidth
- Bandwidth variability
- Latency
- Power consumption

Network Bandwidth - WiFi

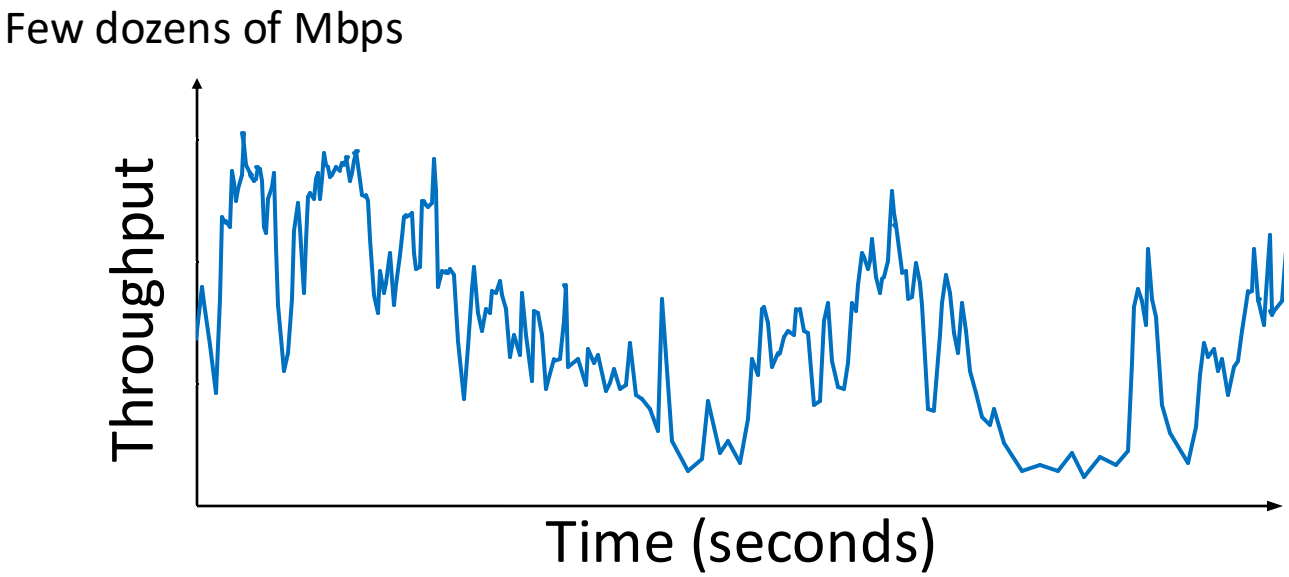


Network Bandwidth - Cellular



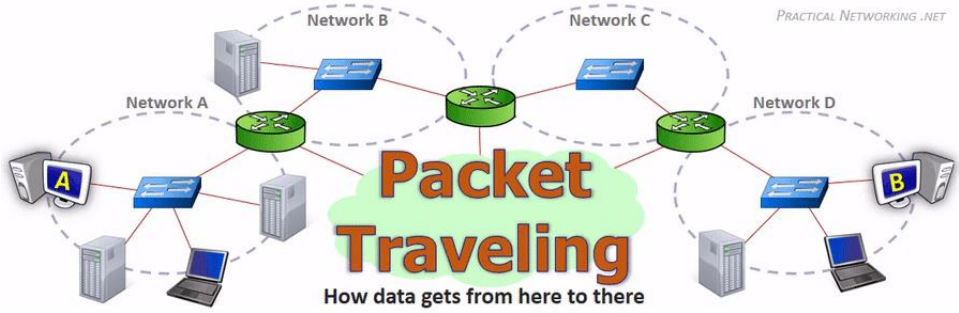
Network Bandwidth

A high quality XR system requires a few dozens of Gbps to stream interactive 3D content



Network Latency

- Processing
- Transmission
- Queueing
- Propagation



https://www.practicalnetworking.net/series/packet-traveling/packet-traveling/

Network Latency - Processing

- Application processing
  - Preparing and packaging data into bits and packets
- Network stack
  - Packets are copied and processed at each layer before passing to the transmission (physical) layer
- Example Application
  - Video Streaming

Network Latency - Transmission

- Radio takes time to transfer bits onto the transmission medium
  - Wire
  - Wireless – WiFi/Cellular Radios
- Depends on the device and chip

Network Latency - Queueing

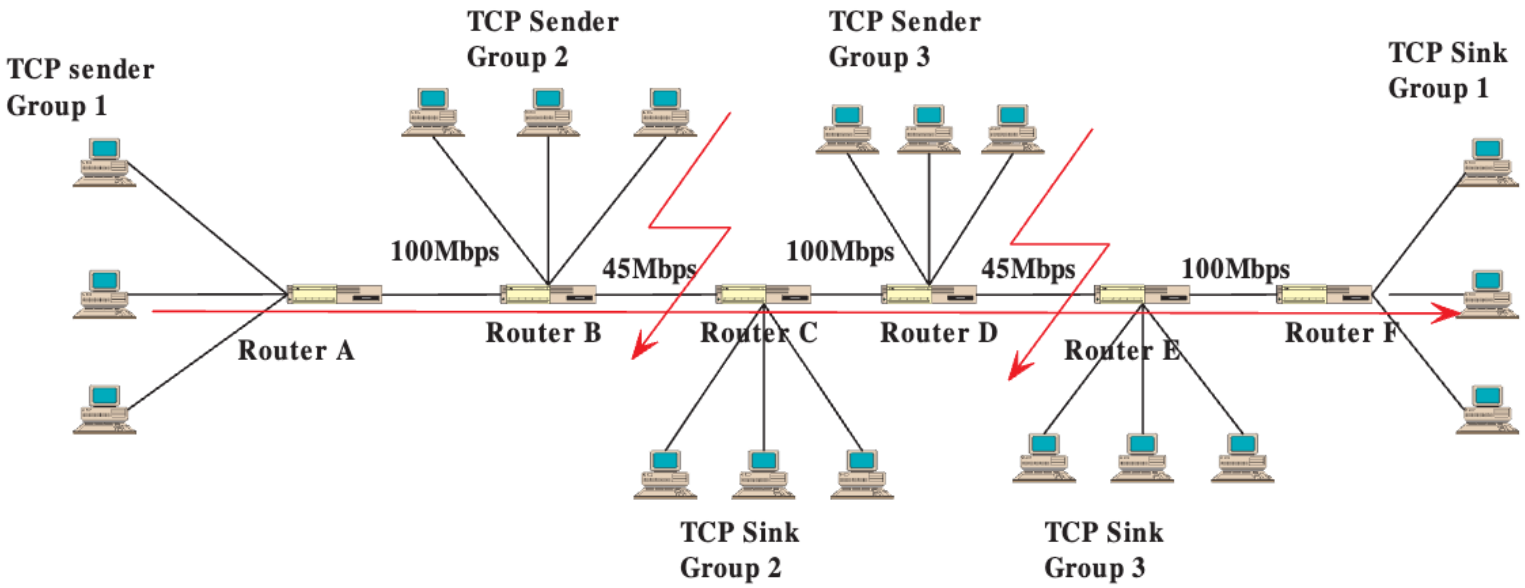
- Routers often have large queues of packets
  - Shallow buffers
  - Deep buffers
  - Trade-offs?

Network Latency - Propagation

- Light speed is the limit on packet time of flight
  - Boston to London – 3000 miles, ~16ms
  - Boston to Bombay – 10000 miles, ~40ms (ideal)
  - Impossible to send a packet faster than this latency

Routers and Switches as Bottlenecks

Packets are transported from place to another through multiple hops



Network and Application Synchronization

- Application vs. TCP congestion control
  - Mismatch in sending data rate

- Example
  - Video streaming application wants send at 100Mbps rate
  - Transport protocol sends at 10Mbps – Packet drops
  - Solution?

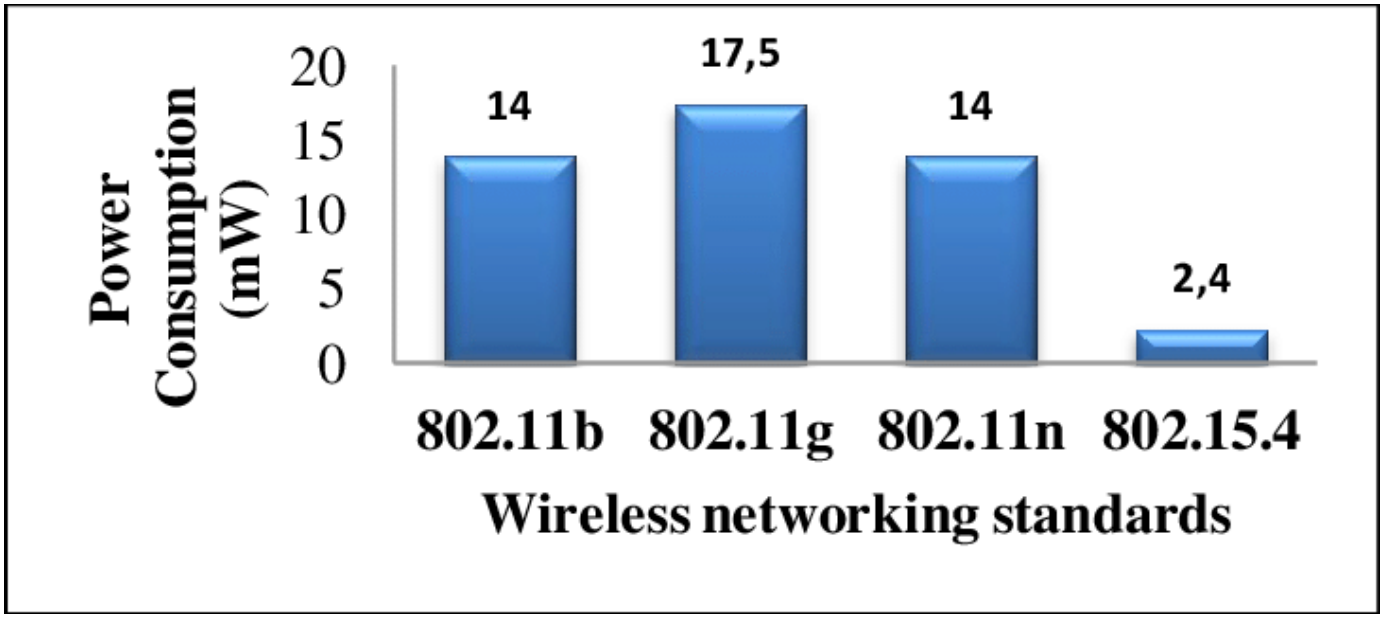
Power Consumption

- Application-level power consumption

- Example
  - 3D rendering
  - Video encoding or decoding
  - Display

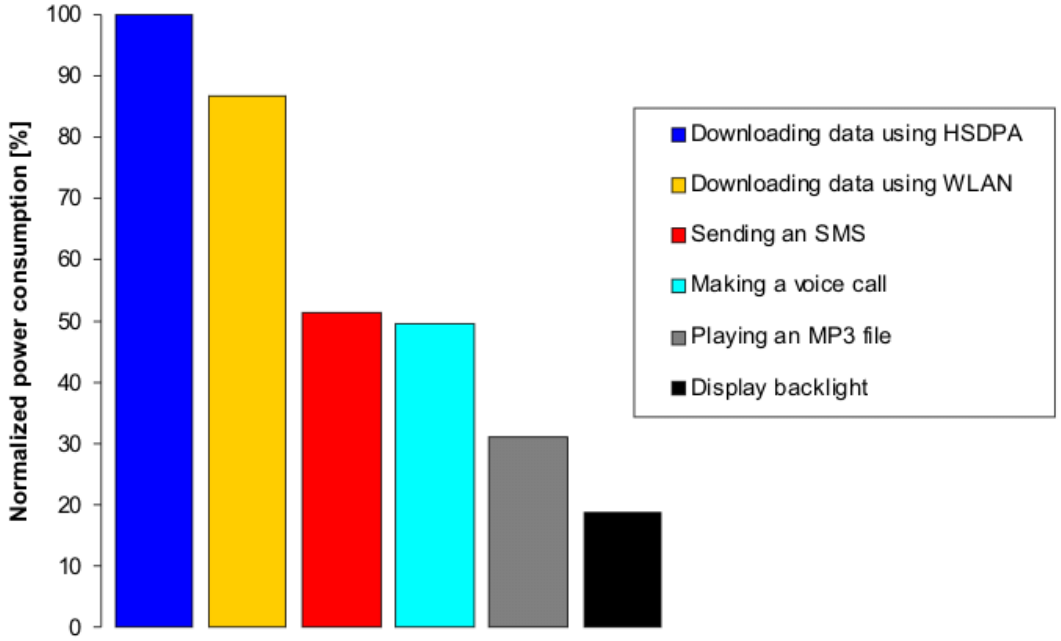
Power Consumption

- Network packet processing
- Radio is one of the most power-hungry components



Power Consumption

- Cellular radio consumes more power than WiFi



Perrucci et.al 2009

Summary of the Lecture

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