HoloCast+: Hybrid Digital-Analog Transmission for Graceful Point Cloud Delivery with Graph Fourier Transform

Takuya Fujihashi\textsuperscript{1}, Toshiaki Koike-Akino\textsuperscript{2}, Takashi Watanabe\textsuperscript{1}, Philip Orlik\textsuperscript{2}
\textsuperscript{1}Osaka University
\textsuperscript{2}Mitsubishi Electric Research Laboratories

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Background

- Volumetric media streaming
  - Reconstruct 3D scenes with full parallax and depth info.
  - Applications: entertainment, medical imaging, augmented reality

- Important technique for the post-COVID society
  - Realize 3D/holographic teleconference
  - Smooth communications between remote people
Point Cloud

- Typical data structure for 3D scene
  - Consist of numerous and irregular structure of 3D points
  - Each point has 3D coordinate (x, y, z) information

- Existing schemes use digital-based compression
  - Encoder sets coding parameters based on the current wireless channel quality

![Diagram of Point Cloud processing stages](image)

- Octree
- Quantization (Pruned tree)
- Entropy coding
- Modulation & Channel coding

Point Cloud
Issues of digital-based wireless point cloud streaming

1) Cliff due to errors in bit-stream (cliff effect)

2) Constant due to quantization

Encoder) channel quality is here! Set the best source/channel coding

Wireless Channel Quality (SNR)

Reconstruction quality

High

Low

BPSK

QPSK

16QAM

Channel quality is varying

BPSK

QPSK

16QAM

Time [ms]

200ms

High

Low
Goal

Ideal:
1) **No cliff**,  
2) **Graceful** improvement

Wireless Channel Quality (SNR)
Purpose

- Our study tackles following challenging issues
  1. Prevent cliff effect
  2. Gracefully improve 3D reconstruction quality

- We propose novel schemes, **HoloCast** and **HoloCast+**, for wireless point cloud delivery

  - **HoloCast** [1]: first scheme to introduce **graph-based** analog coding for graceful point cloud delivery
  - **HoloCast+**: first scheme of **hybrid digital-analog (HDA)** point cloud delivery
HoloCast [1] : Graph-based point cloud delivery

- Regard 3D points as graph signals
  - Conventional images and videos: horizontally and vertically ordered signals
  - Volumetric: non-ordered and irregular signals
- Introduce GFT for graph signals to exploit correlations in graph-domain

HoloCast [1] : Graph-based point cloud delivery

- Near-analog modulation realizes graceful quality improvement according to wireless channel quality

Original Point Cloud

Graph Construction → GFT → Power Allocation → Near-analog modulation

Power allocation (scale up × 10)→ 100
Noise (-10) → 90
Scale down /10

Original Transmitted Received Decoded
Issue of HoloCast

- Graceful, but inefficient owing to large signal energy

HoloCast+ extends HoloCast to hybrid digital-analog transmission
HoloCast+: Overview of sender

1. Encode point cloud to generate bit stream
   - Channel coded, interleaved, and modulated
2. Calculate **residuals** from original and reconstructed point cloud
   - Residuals are modulated by analog encoder
3. Assign transmission power to digital and analog symbols before superposition of both symbols
HoloCast+: Overview of receiver

1. Digital and analog symbols are decoded separately
   1. Soft decision decoder for digitally-modulated symbols
   2. Blind data detection for analog signal reconstruction
2. Add reconstructed residuals to the output from the digital decoder for final output
Evaluation

- **Reference schemes**
  - Digital-based: BPSK, QPSK
    - Use octree-based coding
    - Use rate-1/4 and 1/2 convolutional codes
  - HoloCast
  - HoloCast+ (Proposed)

- **Reference point cloud**
  - pencil 10_0 (2731 points)
  - pencil__9_0 (6712 points)
  - pencil__4_0 (5712 points)
  - pen__4_0 (23649 points)
  - milk_color (13704 points)

- Metric: symmetric mean square error (MSE) and peak signal-to-noise ratio (PSNR)
3D reconstruction quality of 3D coordinate attributes

Cliff Effect

Graceful improvement
3D reconstruction quality of color attributes

Still realize graceful improvement

- BPSK 1/4 (Identity)
- QPSK 1/2 (Identity)
- BPSK 1/4 (GFT)
- QPSK 1/2 (GFT)
- HoloCast
- HoloCast+
Visual Quality

Original  QPSK 1/2  HoloCast  HoloCast+
Conclusion

- We designed graceful point cloud delivery
  - HoloCast: first scheme to introduce graph-based analog coding for graceful point cloud delivery
  - HoloCast+: first scheme of HDA point cloud delivery

- Potential applications
  - AR, VR, 3D display, LiDAR
  - 3D/Holographic teleconference

- Question? – Welcome!
  - fujihashi.takuya@ist.osaka-u.ac.jp