a single frame that is statically displayed to satisfy a minimum user experience requirement.

5 RELATED WORK

Compression of PtCl and 3D mesh has been well investigated in the literature. In particular, several variations of octree-based (§2) compression have been proposed (*e.g.,* [7, 11, 24]). Kammerl *et al.* extended the octree to perform inter-frame compression for real-time 3D data acquisition [12]. Another inter-frame compression scheme based on iterative closest points (ICP) algorithm was proposed by Mekuria *et al.* [18]. We refer readers to [17] for 3D mesh compression.

Streaming volumetric videos is a new topic. Very recently (2018), Park *et al.* [21] sketched a greedy volumetric video streaming algorithm that considers video bitrate, visibility, and the distance from the viewer. DASH-PC [10] extends DASH to PtCl streaming. It proposes sub-sampling dense PtCls to create different quality representations, as well as designs a DASH-style manifest file format. Compared to both proposals, Nebula is a holistic PtCl video streaming system designed specifically for mobile devices, with unique features such as edge assistance, perceived delay reduction, principled rate adaptation, and incremental quality upgrade.

QoE Metrics have been well studied for regular videos, but remain an open problem for volumetric video streaming. Most of the existing work focuses on assessing the quality of a static 3D model, with the reference model known, using simple metrics such as point-to-point distance or angular similarity [4]. For volumetric videos, researchers have done limited subjective tests or simply used the above per-frame distortion metrics [6]. However, it is well known that (for regular videos) traditional image quality metrics such as PSNR and SSIM do not correlate well with subjective measures (QoE). The same likely holds for volumetric videos. We thus plan to thoroughly investigate their QoE metrics by considering the impact of, for example, stalls, quality changes, viewing distance, and the motion-to-photon delay.

VR and 360° Video Streaming Systems. Finally, there exist a plethora of systems on mobile VR and 360° video streaming. Representative research prototypes include FlashBack [5] (boosting mobile VR quality through caching rendered scenes), Furion [16] (cloud-assisted VR through separating foreground and background content), Rubiks [9] (tile-based 360° video streaming), and Flare [22] (another viewport-adaptive 360° video streaming system for smartphones with further optimizations). Compared to VR and 360° video streaming, PtCl streaming faces numerous challenges such as poor decoding performance on smartphones, a lack of rate adaptation algorithms, and the difficulty for predicting the 6DoF viewport movement, as well as unique opportunities such as the specific data structure of PtCl data. All these challenges and opportunities are considered in Nebula's design.

6 ON-GOING WORK AND CONCLUSION

Motivated by the poor PtCl streaming performance on smartphones, we present Nebula, a holistic system for high-quality mobile volumetric video streaming. Our central idea is to use an edge server to judiciously transcode a PtCl stream into a regular pixel-based video that can be efficiently transmitted to and decoded by mobile devices. We further describe various optimizations such as incremental quality upgrade, motion-to-photon delay reduction, principled QoE-aware rate adaptation, and viewport adaptation.

We are now prototyping Nebula according to our design detailed in §4, as well as conducting the IRB-approved user studies as described earlier. We will thoroughly evaluate Nebula using PtCl video content on real mobile devices and under diverse network conditions. We also plan to extend Nebula to support 3D mesh based volumetric videos.

ACKNOWLEDGEMENTS

We thank the anonymous reviewers for their comments. We also thank Dr. Aakanksha Chowdhery for shepherding our paper.

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