Towards Achieving Immersive Holographic-Type Communication

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Abstract

This paper focuses on video streaming over telecommunication networks, taking the important evolution towards network softwarization into account. The importance and the opportunities provided by volumetric media delivery will be outlined by means of examples. The most appropriate management platform design for volumetric media delivery and the various challenges and possible approaches will be highlighted next. Finally an overview of research challenges and opportunities will be presented to generate further collaborative research in this area of research.

1 Network resource management

Network resource management is of prime importance for telecommunication network operators, equipment manufacturers and data center providers as it allows to (i) make efficient use of the available resources, (ii) offer service guarantees, and (iii) make sure that services can be delivered with high quality of experience to end users. Given the strong competition in the telecommunication domain and the increasing expectations of end-users, network operators and providers need reliable network resource management algorithms and methodologies. Ad hoc solutions often result in low resource utilization and high overhead, given the dynamic nature of resource availability and inherent complexity of resource allocation algorithms. Examples of resource allocation algorithms are reported upon in [15] and [16]. Smart city use cases, where resource allocation is an important topic, are reported upon in [16, 17].

2 Softwarized Networks

Softwarized networks bring virtualization concepts to the network and have proven to be particularly important for the industry, including telecommunication operators, cloud infrastructure and service providers. We refer to [11, 12, 22] for more information. The main advantages for network operators of softwarized networks is that they allow for (i) replacement of dedicated hardware with generic hardware and software-based functions, (ii) maximization of resource utilization and optimize energy usage, (iii) faster and easier deployment, configuration, and updating of network functions, and (iv) support for the Network-as-a-Service business model. The main advantages for service providers
are that softwarized networks allow for (i) dynamical scaling of the network, computing and storage resources based on the service requirements, and (ii) reduced time to market for services.

3  Adaptive service delivery

Adaptive video delivery [3, 5, 7] is an important and widely deployed technology, where the video clients estimate the most appropriate video quality levels of the video segments and inform the server nodes about the quality level to select. Optimization of the delivery of adaptive video streaming services by in network optimizations [20, 21] is often considered by network and service providers. A framework for mobile augmented reality applications is published in [18].

4  Volumetric media

4.1  Overview

Volumetric Media is a technique that captures a three-dimensional space and often refers to technologies such Virtual Reality and Augmented Reality. Immersive means strong absorption into a technology for video streaming. Volumetric media are also often referred to as holograms. In a hologram, parallax is added compared to a traditional 3D image. Parallax is the apparent displacement of an object because of a change in the observer’s viewpoint. As a consequence, for hologram creation and consumption, 6 degrees of freedom (also referred to as 6DoF) are needed. In contrast, 2 dimensions are used for traditional video streaming, e.g. for currently widely deployed teleconference applications.

4.2  Uses cases

Important use cases for volumetric media delivery include (i) holographic collaboration and conferencing [9], (ii) tele-surgery and remote patient monitoring [10], and (iii) remote industrial monitoring and management [11].

4.3  Hologram BW requirements

The bandwidth requirements for volumetric media delivery are described in [4] for HD, 360 degree (4K), 360 degree (16K), point cloud based video and light field based video. Based on these, we can conclude that dynamic point-cloud scenes require a significant amount of data, for instance 20 GB/s when 4 point cloud objects are displayed simultaneously. Typically holograms are generated through a local application, because the current bandwidth requirements (Gb/s) are too high for remote access. Advanced compression techniques will be needed to significantly reduce the bandwidth requirements.
4.4 Subjective quality study

In order to evaluate the perception of users of volumetric media when the content is streamed using adaptive streaming, we performed a subjective study with 30 users. Three types of video content were composed by four different point cloud objects presented on a flat screen and streamed using different bandwidth and bitrate allocation configurations. The main observations are that end-user based or over-the-top optimizations are currently not sufficient for the end-user, because these techniques do not contribute to the low latency requirements. For these reasons, a cross-layer based end-to-end architecture for volumetric media delivery will be needed, as detailed further below in this paper.

5 EU Spirit project

The EU Horizon Europe SPIRIT project (2022-2025) focuses on designing a scalable platform for innovations on real-time immersive telepresence. In particular, the following use cases are considered:

- Real-time human-to-human interactions
  - holographic conversations,
- Real-time human-machine interactions
  - Human-initiated: multi-site machine supervision, supported by autonomous mobile robots for intralogistics,
  - Machine-initiated: autonomous mobile robots alert humans to solve contextual problems.

The project organizes two open calls for third parties to evaluate the designed platform on the project testbed. Target application domains are: healthcare, retail, education, training, entertainment, manufacturing, and tourism.

6 Cross-layer architecture

In order to achieve a performant and high quality immersive volumetric delivery, optimizations are needed at three different levels: (i) end-user optimizations, (ii) over-the-top and transport optimizations and (iii) novel network architectures. These three levels are detailed below.

6.1 End-user optimizations

Client-side optimizations include (i) viewport prediction, (ii) synchronization of feeds and (iii) cybersickness assessment and avoidance strategies. Server-side optimizations include for instance (i) 3D tiling and (ii) multiple representations encoding.
6.2 Over-The-Top and Transport optimizations

Three are two flavors of traditional streaming: (i) adaptive streaming: mainly for on-demand streaming with no real-time encoding and (ii) live streaming, where WebRTC and QUIC are often used for browser-based real time streaming. The following Over-The-Top and transport layer optimizations are useful for volumetric media streaming:

1. low latency transport (combining advantages of TCP and UDP) (HTTP over QUIC, for example),
2. more intelligent buffering techniques (window based) [13],
3. smarter retransmission techniques (including HTTP push) [14],
4. adaptive partially reliable delivery of immersive media over QUIC-HTTP/3.

6.3 Novel network architectures

Two main innovations on the network layer are expected, which are very beneficial for volumetric media delivery:

1. Service Function Chaining: in this approach, the application for volumetric streaming is built by implementing several VNFs (Virtual Network Functions) and executing them as a SFC (Service Function Chain) [22]. Examples of VNFs are: (i) software component for stream capturing and scene merging, (ii) VNF for compression and encoding, (iii) VNF for stream transport and caching, (iv) VNF for view prediction and decoding, and (v) VNF for rendering and QoE (Quality of Experience) monitoring. The individual VNFs are executed on the most appropriate location (cloud, core network, edge, or fog) based on dynamic placement algorithms, as for instance described in [22]. Other examples of placement algorithms are reported upon in [1] and [19].

2. Distributed Network Architectures: in addition to SFC-based networking, networks will need to modernize to fully decentralized architectures where delays in some flows do not affect others. In Software Defined Networking, the current central solutions can evolve to new hierarchical and fully decentralized approaches, to enable lower flow setup times, as described in [23]. Examples of hierarchical network management systems are reported upon in [24, 25].

As an example framework, SRFog [22] considers Fog Computing and micro-services for the VNF design. SRFog follows the Kubernetes architectural model and adopts container-based service chains and traffic flow optimization based on Segment Routing. The typical maximum end-to-end latency objective for immersive video delivery is 20 milliseconds. There is important ongoing work on taking latency and network bandwidth effectively into account in the Kubernetes container scheduling process, which is very beneficial for the management of volumetric media delivery streams.
7 Conclusions and future work

In order to be able to fulfill the quality expectations of users of future immersive media, there is a need for optimizations at all elements of the transmission chain as well as at all levels of the protocol stack. With the elements above, it is clear that we are on our way to achieving this. However, there is still a lot of room for research. At the end-user fast encoding strategies, novel quality modelling as well as prediction and adaptive bitrate selection approaches will be needed to adapt the systems to the needs and requirements of the users. For the network domain, transport protocols will need to be made faster and more accurate. Moreover, network architectures will need to be updated taking decentralization and function placement into account.

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