In Network Computing Enablers for Extended Reality
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Abstract

   Augmented Reality (AR) and Virtual Reality (VR), combined as Extended
   Reality or XR, challenge networking technologies and protocols
   because they combine the features of fast information display, image
   processing, computing and forwarding. This document presents some of
   these challenges and how adding computing in the network could
   respond to them.

Table of Contents

[1](1). Introduction

   Virtual Reality (VR) and Augmented Reality (AR) taken together as
   Extended Reality or XR are at the center of a number of technological
   advances in many different fields, including not only gaming and
   entertainment but immersive journalism, remote diagnosis and
   maintenance, telemedicine, manufacturing and assembly and smart
   cities.

   But with the emergence of the edge and the programmability of network
   elements all the way from the data center to the users the
   possibility of creating networked, multiparty/multisource and
   interacting XR comes closer to reality. This document wants to
   review what is necessary for the current localized and cloud enhanced
   XR to evolve to a more distributed and edge centric architecture to
   support advanced immersive application and services. It assumes that
   network programmability will enable to tailor the network to the XR
   requirements. This document is about requirements not solutions per
   se but will mention work that has already been done towards a more
   networked XR including Information Centric architectures, Artificial
   Intelligence and in network coding. The networked functionality
   should enable to supplement local XR services and devices while
   keeping the very low latency and the very high data rates that are
   required by XR.

   This document is intended as informative to both the networking and
   application research community. It does not address a specific
   network layer or protocol but provides architecture and system level
   specifications and guidelines. For example:

      Latency: the physical distance between the XR content cloud of AR/
      VR and users are short enough to limit the propagation delay to
      the 20 ms usually cited for XR applications mixed for example with
      IoT devices and sensors delay reduction for range of interest
      (RoI) detection.

      Applications: better transcoding and use of compression
      algorithms, pre-fetching and pre-caching and movement prediction.

      Monitoring: implement management and metrics gathering closer to
      where the XR services are consumed.

      Network access: push some networking functions in the kernel space
      into the user space to enable the deployment of stream specific
      algorithms for congestion control and application-based load
      balancing based on machine learning and user data patterns.

[1.1](1.1). Requirements Language

   The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",
   "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this
   document are to be interpreted as described in [RFC 2119](RFC 2119) [[RFC2119](RFC2119)].

[2](2). Definitions

      - 360-degree video: 360-degree videos, also known as immersive
      videos or spherical videos, are video recordings where a view in
      every direction is recorded at the same time using an
      omnidirectional camera or a collection of cameras. 360o video is
      outside the scope of this document.

      - AR: Augmented Reality (AR) is a live direct or indirect view of
      a physical, real-world environment whose elements are augmented by
      computer-generated input such as sound, video, location or
      graphical data. It is related to a more general concept called
      mediated reality [MEDIA], in which reality is modified (diminished
      or augmented) by computer-generated imagery.

      - VR Virtual Reality (VR): uses software-generated realistic
      imaging, sounds and other sensor inputs to replicate a real or
      imaginary setting, to simulates a user's physical presence in this
      environment and provide an immersive experience that enable the
      user to interact with objects and move within this space.

      - XR: extended reality is used to address both AR and VR together.

3. Extended Reality and In-Network Computing

   XR is an example of the Multisource Multidestination Problem that
   combines video, haptics and tactile experiences as well, in
   interactive or networked mode multiparty and social interactions.
   Thus, XR is difficult to deliver with a client-server cloud-based
   solution as it requires a combination of stream synchronization, lows
   delay and delay variations as mentioned above as well as means to
   cover from losses and provide optimized caching in the cloud and
   rendering as close as possible to the user at the network edge.

3.1. XR Network Requirements

   To deliver the XR experience, there is a need to achieve complete 6
   degrees of freedom meaning the 3 axes for body movement (x,y,z) plus
   pitch, yaw, rotation of the head all of which must be fulfilled in
   real time. Low delay, low loss and low delay variation are needed to
   avoid sea sickness symptoms if the image does not follow the movement
   [CABLE].

   But this is not the only difficulty, as there is also the need to
   provide real-time interactivity for immersive sports, mobile
   immersive applications with tactile and time-sensitive data and high
   bandwidth for high resolution images. Since XR deals with personal
   information and potentially protected content (in entertainment and
   gaming) XR must also provide a secure environment and ensure user
   privacy. And of course, the sheer amount data needed for and
   generated by the XR applications will use recent trend analysis and
   mechanisms, including machine learning to find these trends and
   reduce the size of the data sets [INTER].

   Shared and global immersive experiences require interconnected,
   distributed and federated XR nodes. The requirements can be
   summarized as:

      - Allow joint collaboration in VR.

      - Provide multi-view AR.

      - Add extra streams (IoT) to AR and VR experiences across data
      intensive services, manufacturing and industrial processes.

      - Provide "Social Television" experiences and global viewing and
      experience rooms.

      - Enable multistream, multidevice, multidestination applications.

      - Use new Internet Architectures at the edge for improved
      performance and perfromance management.

      - Integrate with holography, 3D displays and image processing
      systems [CABLE].

3.2. In-Network Computing Advantages in XR

   One aspect of the push of XR to the edge is of course to take
   advantage of the cloud/edge continuum and functional decomposition to
   provide lower latency services and enable the development of new
   applications . While this is very promising the question of the
   localization of the networking resources in order to provide the
   service becomes an essential component of the overall architecture.
   But it is not only finding the best geographical location but also
   providing the right level of reliability when one or more location is
   not available especially for mission critical services in medicine or
   manufacturing. And it does not mean only data laid distribution but
   also ensuring the availability of the right computational
   capabilities. The optimization of the location and type of the
   required resources for the multisouce, multidestination, mutiparty,
   multi-input XR applications can use AI and ML, and advanced load
   balancing and distributed network principles. There is a need for
   more research in such resource allocation problems at the edge to
   enable autonomous node operation and quality of experience
   [SOL].These are of course multi-variate and heterogeneous goal
   optimization problems requiring advanced analysis with fast
   converging algorithms [MULTI][PACKET]. This is essential for the
   federation of nodes to provide the required experience.

   Of course, image rendering and video processing in XR leverages
   different HW capabilities combinations of CPU and GPU. Current
   programmable network entities need to be evaluated to see if they can
   be sufficient to provide the speed required to provide real-time
   rendering and execute complex analytics: P4 for example does not
   support the floating-point operations necessary for advanced
   graphics.

   Finally, dynamic network programmability could enable the use of
   joint learning algorithms across both data center, edge computers and
   goggles or glasses to allocate functionality and the creation of semi
   permanent datasets and analytics for usage trending. In the end, the
   use of computing or networked XR will enable the allocation of
   control, forwarding and storage resources and related usage models
   when needed by the application. This may mean re-evaluating the
   distribution of functionalities between datacenter and edge with less
   critical elements rendered in the cloud combined with a better
   understanding of the operational decomposition of the XR experience

to allow the use of novel data structures, three-dimensional modeling
and image processing algorithms.

Other advantages of adding computing to networked XR include:

   - Multicast distribution and processing as well as peer to peer
   distribution in bandwidth and capacity constrained environments.

   - Evaluation of local caching and micro datacenters with local or
   cloud-based pre-rendering.

   - Trend or ML based congestion control to manage XR sessions
   quality of service.

   - Higher layer protocols optimization to reduce latency especially
   in data intensive applications at the edge.

   - Trust, including blockchains and smart-contracts to enable
   secure community building across domains.

   - Support for nomadicity and mobility (link to mobile edge).

   - Use of 5G slicing to create independent session-driven
   processing/rendering.

   - Performance optimization by tunneling, session virtualization
   and loss protection.

[4](#). XR in Data Intensive Services and Applications

In-network computing is essential for data reduction and multistream
low latency services at the edge where moving the data to the cloud
is either requiring too much bandwidth or adding unacceptable
latency. Examples of these services included industrial processes
monitoring, AR-aided design and fabrication and AR/VR supported
medical interventions.

[5](#). Enabling Technologies

This section presents some salient research that will lead to in-
network computing becoming a major enabler of networked XR.

NOTE: more information and added sub-sections will be added in future
versions of the draft with the collaboration of co-authors in the
specific research areas.

5.1. Information Centric Networking (ICN) and Named Data Networking (NDN)

The Named Data Networking (NDN) architecture, one architecture of
ICN, is particularly well suited for the multisource multi-
destination architecture of XR because it allows to create the
content experiences based on their components names not a location or
pointer to a location hence provides a natural functional
decomposition. ICN allows content delivery to evolve from single,
context-independent streams to context-dependent Information
components that can adapt dynamically to the changes necessary to
maintain the immersive nature of the experience and be delivered
efficiently. The combination of interest messages to signal what
content is needed combined with the data responses help to coordinate
the different streams and multiple users (pull mechanisms). The ICE-
AR [ICE] project already mentions a concept of acceleration as a
service: the exploration of the design and the usage of computation
at the edge including the wireless edge.

For XR, ICN also allows to develop robust and resilient networking
while allowing application developer to continue using known
programming model [RICE]. This is important for the XR developers
community that come from the entertainment, gaming or other non
networking specific industries and could enable ICN and XR to coexist
in user devices (the ultimate edge). NDN concepts are already
integrated to distributed video distribution with trust mechanisms
(see section below) such as smart contracts on the blockchain to
proof of origin and destination sent along with interest messages
[HUITX].

5.2. Network Coding

Networked XR requires the synchronization of multiple streams but
with its delay sensitivity the use of buffering schemes to achieve
this synchronization is impractical. At the same time the need to
maintain high data integrity means that packet losses also need to be
limited. Network coding has proven very useful to achieve both these
goals in commercial streaming services like Netflix, is being added
to protocols like QUIC, multi-stream services such as Social
Television [SOCIAL] and other data-centric low latency applications.
This avoids being reliant on complex synchronization algorithms. The
many XR servcies are constrained in latency and loss budgets
especially in mission critical applications hence even the delay due
to encoding and decoding operations needs to be minimized. Hence the
idea of in-network coding and re-encoding to adapt to dynamic network
conditions, not just end to end, can be used to ensure on time packet
delivery with loss recovery. In network encoding needs the type of
programmability that COIN provides and the developement of

programmable switches and the P4 language may allow to create very
efficient in-network coding even considering the limitations of the
language Note: references to be added.

[5.3](5.3). Blockchains and Distributed Trust

If XR is to be integrated at the edge of the network to provide the
required delay and loss guarantees, then relying on centralized
mechanisms for trust is non-realistic. Traditional centralized
mechanisms to discover and admit nodes to the network, to provide
access right and name resolution need to be updated to be used in the
dynamic XR environment.Blockchain technology, with operations
performed at the edge and in a decentralized way is fast becoming a
major scalable means of providing trust and validate provenance in a
large number of applications including those on the XR portfolio.

Smart contracts (on the blockchain) supply a mechanism to provide the
trust and validation for XR edge nodes. A new XR participant node is
admitted after it has committed to a smart contract that contains the
rules and mechanisms to distribute content via this node in a trusted
and secure way. This constitutes its proof of validity. After a
node is admitted, it will can then provisioned with the appropriate
software to become fully operational to provide the XR experience.
Newly admitted nodes will be inserted in the general ledger on the
blockchain enabling other nodes to discover them, and hence, to form
a trusted network. A name resolution authority can also be provided
by the blockchain to manage and validate the origin of the content,
the proof of origin, and to provide the ability to search such
content. The proof of origin can also be used to prevent some
content from reaching one or more nodes and implement content
filtering based on trusted authorities. This is useful not only for
content packets but also for packets capable of modifying the node
operations. Finally, when some content reaches a specific
destination, it can be verified against the content rules of the
reached node even and before it is sent to the application; this
allows to provide a proof of delivery for the content and enable to
generate statistics, performance metrics and enable the nodes to
adapt to the XR requirements.

All of the above assumes that the nodes can implement the functions
needed by the blockchain hence once again infers that there is enough
computing power in the nodes to perform these operations. At this
point both proof of concept and proof of every are limited due to the
added overhead and the size of the blockchain. As distributed
blockchains and COIN continue to evolve this should continue to be a
field of interest for the development of secure and private XR
experiences.

6. Conclusion

More and more applications and service are being developed and
deployed that use or will use combinations of AR and VR, XR, along
with extra stream from sensors and IoT devices. And many of these
applications require to be deployed over a network because of their
interactive or multiparty nature. In that context, it not uniquely
necessary to move functionality to the network but to carefully
evaluate which elements to locate in network nodes, where these nodes
are and what computational support they need to support the XR
experience. Hence, it is believed that a great enabler of networked
XR is the capability to co-locate programmable elements in the XR
network node to respond to the dynamics of the services in an
efficient, resilient and secure manner.

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