Metaverse and Networking

draft-fmbk-icnrg-metaverse-01

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Information-Centric Metaverse: Background

draft-fmbk-icnrg-metaverse aims to explore the new challenges for the transport network brought by the development of Metaverse.

"Metaverse" mainly include the notion of shared, interoperable, and persistent XR.

- Different solutions are being proposed to extend existing Internet protocols, e.g.
  - providing more deterministic communication services through resource reservation and scheduling,
  - enabling the network to understand application requirements and to provide corresponding QoS,
  - extended overlay infrastructure for reducing latencies for CDN-like distribution etc.

- Alternatively, one might also take a more principled approach and conceive the Metaverse and the future web as a fundamentally information-centric system.

Requirements and Gaps

The main requirements of VR and AR to networking are:

- low latency and high-speed transport to reach services in one-hop and for real-time interactions;
- intelligent control and SLA real-time monitoring to manage network resources and source/route re-selection;
- decentralization and Edge Services by positioning the data close to the user;
- reducing data sizes through resolution changes, compression, and more efficient encodings.

A paper (ACM IMC '22 - Are we ready for metaverse?: a measurement study of social virtual reality platforms) performed measurements with five popular social VR platforms.

- The experimental results revealed that all these platforms face fundamental technical challenges:
  - Poor scalability: throughput, end-to-end latency, and on-device computation resource utilization increase almost linearly with the number of users.
  - Noticeable load and reduced achievable video rendering frame rates and considerable network utilization even with smaller numbers of users.

Current and Emerging Approaches

Different IETF technologies have been proposed to address some of the issues:

- MPTCP (RFC8684) and MPQUIC (draft-ietf-quic-multipath) can help to maximize throughput.
- Dynamic Adaptive Streaming over HTTP (DASH) helps to improve the viewport quality of immersive videos by refining the tiles delivery. It is client-driven with less control on server side.
- Media over QUIC (MoQ) (draft-ietf-moq-requirements) and QuicR (draft-jennings-moq-proto) use similar concepts and delivery mechanisms to those used by CDN and named objects.
- The APplication-aware Networking (APN) aims to develop a framework to enable fine-granularity network service provisioning within the network domain (draft-li-apn-framework).
- The Computing-Aware Traffic Steering (CATS) analyzes the problem on the edge node, which makes a decision based on metrics, and then steers the traffic to the best service node.

In all of these approaches, the Metaverse is considered as an overlay application with corresponding infrastructure dependencies.

Opportunities and Challenges for ICN

Information-Centric Networking (ICN) introduces named information objects, e.g. media contents, as the central concept as opposed to host-to-host communication (RFC7927).

The Metaverse can be seen as an information-centric system where applications participate in granular 3D content exchange, context-aware integration with the physical world.

- Many applications already work with data-oriented paradigms. Mapping them to a host-centric network model creates complexities and robustness issues.
- The overlay approach to deal with real-time interactive media adds significant complexity.
- It is needed a fine-grained, hierarchical media exchange for low-latency interactive communication that enables scalable multi-destination distribution, and in-network replication.

Issues with today's technologies creates research opportunities for the ICN community:

- Scalable multimedia communication;
- Interaction with applications;
- In-network computing;

Scalable multimedia communication

Issues today

- Low-latency live streaming is not easy and not efficient in the Internet today. DASH incurs high latencies.
- What is needed:
  - fine-granular media distribution that supports both interactive and streaming;
  - scalable multi-destination distribution, i.e., some kind of in-network replication;
  - ability to leverage wireless broadcast such as 5G Broadcast; and
  - support for heterogeneous devices and edge networks, i.e., different quality layers, possibly dynamic transcoding.

ICN Support and Research Opportunities

- multi-destination distribution with automatic in-network replication, aggregation and caching.
- uniform interface for unicast and multicast. IP-multicast issues (inter-domain, routing scalability) do not apply
- Wireless broadcast could be leveraged where available, without requiring application-awareness in edge routers.
- Receiver-driven operation conducive to supporting different quality levels, like in DASH today.
- Validation of consumer mobility in ICN.

Interaction with applications

Issues today

- In Metaverse applications, data can potentially be shared efficiently between nodes and within one node/process. Connection-based communication models make it hard/impossible to do so.
- Application layer data structures in VR (3D models, scene descriptions) are based on object hierarchies. Connection-based systems may not be able to take advantage of it.

ICN Support and Research Opportunities

- ICN generally enables direct data-oriented communication: just names and objects so that location, storage contexts become less relevant. In addition ICN provides:
  - named-based APIs to applications;
  - support for object collections through manifests;
  - additional "middleware" such as dataset synchronization; and
  - data-sharing support, which has benefits beyond networking, e.g., zero-copy sharing in processes etc.
- Information-centric hypermedia concepts, i.e., linking between objects/collections.
- Concepts for dealing with "mutable objects" (or mutable "information").
- The relationship between application-layer data-oriented operation and network-layer.
- Concepts and mechanisms for privacy, selective attention, content filtering, and autonomous interactions, as well as ownership and control on the publishing side.

In-Network Computing

Issues today

- In-network computing today is typically limited to coarse-grained CDN-style computing, include Multi-Access Edge Computing.
- Current trust and security frameworks require TLS connection termination, but it represents an overlay approach, which is not conducive to low latency communication.
- Dynamic, just-in-time, instantiation of computing function on application-agnostic platforms is not available.

ICN Support and Research Opportunities

- The named-data approach is generally useful for distributed computing.
- ICN's security model makes possible to do on-path computing / data transformation securely
- discovery of functions and request forwarding can be punted on regular ICN mechanisms (name-based forwarding).
- Robust distributed computing interaction models (e.g. REST) should be further developed.
- Specific approaches such as in-network media transcoding should also be investigated.

Considerations on Metaverse ICN

- ICN communication facilitates the assumed Metaverse requirements: stateful forwarding layer can help reducing overlay complexity, e.g., intrinsic multi-destination delivery feature (with uniform interfaces for unicast and multicast).

- Metaverse applications may benefit from an ICN's data-oriented approach since it seems a good fit for composing and linking to scene, model descriptions and to manage the hierarchical relationship between different objects/media (USD).

- ICN offers better performance under limited/intermittent connectivity, and in this way it would represent an improvement on the current web adding more resiliency for vehicular and similar applications for Metaverse apps.

- ICN's integrated security framework and its locator-less operation can enable more decentralized system designs which could also be useful for overcoming centralization problems in Metaverse.

- What needs more work is to understand what an ICN-based protocol may look like, namely taking into account other IETF work such as QuicR, APN, CATS,…

Summary and Next Steps

The scope is to start the debate in IRTF (ICNRG) and IETF:

- In general, building applications with ICN today can be done in overlays.
- ICN research has produced some useful protocols and mechanisms.
- There is a need for ICN research and development, for building a complete infrastructure, or systems for content replication, live-streaming (like MoQ).
- Concrete work on Metaverse-like system would be ideal to derive the requirements and provide the testbeds for that.

Comments are welcome!

Thank you