Statement: The Metaverse as an Information-Centric Network*

Dirk Kutscher
HKUST (GZ)
China
dku@ust.hk

Jeff Burke
UCLA REMAP
USA
jburke@remap.ucla.edu

Giuseppe Fioccola
Huawei
Italy
giuseppe.fioccola@huawei.com

Paulo Mendes
Airbus
Germany
paulo.mendes@airbus.com

ABSTRACT

This paper discusses challenges and opportunities of considering the Metaverse as an Information-Centric Network (ICN). The Web today essentially represents a data-centric application layer: data named by URLs is manipulated with REST primitives. However, the semantic gap with the underlying host-oriented transport is significant, typically leading to complexity, centralization, and brittleness. Popular interest in "the Metaverse" suggests that the end-user experience of the Web will evolve towards always-on *eXtended Reality* (XR). With the benefit of a historical perspective, computing advances, and decades of experience with a global network, there is an opportunity to holistically consider the Metaverse not as an application of the current network, but an evolution of the network itself, reducing rather than widening the gap between network architecture and application semantics. An ICN architecture offers the possibility to achieve this with less overhead, low latency, better security, and more disruption tolerance suitable to diverse uses cases, even those facing intermittent connectivity.

CCS CONCEPTS

• **Networks → Naming and addressing**; **Layering**; • **Computer systems organization → Distributed architectures**.

KEYWORDS

Information-centric Networking, Metaverse

1 INTRODUCTION

The Web today has a specific technical definition: it includes presentation layer technologies, protocols, agreed-upon ways of achieving certain semantics such as *Representational State Transfer* (REST) [3], and security infrastructure. However, from a user perspective, it can be viewed as a universe of consistently navigable content and (occasionally) interoperable services. The user experience and architectural underpinnings have evolved in parallel and have influenced each other: for many end users, the Web and the network are synonymous. Rather than building up "Metaverse" as an application domain based on IP, we aim to explore "the Metaverse" as strongly intertwined with ICN, just as the *modern concept* of the Web and its *technology stack* are inseparable for a broad set of applications.

As a placeholder name for a range of new technologies and experiences, "the Metaverse“ is even less well-defined than the Web. We adopt the commonly used concept of a shared, interoperable [2], and persistent XR. Some descriptions and early prototypes for social AR/VR systems [1] suggest leveraging existing Internet and Web protocols to provide Metaverse services, without addressing the technical complexity and centralization of control required to provide the underlying cloud service infrastructure [6].

Here, we do not take as given current designs and deployment models that consider the Metaverse as an overlay application with corresponding infrastructure dependencies, as this exacerbates the current gaps (and the resulting costs and technical complexity) between distributed applications and the underlying network architecture. Instead, we assume a fundamentally information-centric system in which most applications participate in granular 3D content exchange, context-aware integration with the physical world, and other Metaverse-relevant services. "The Metaverse" *is* an information-centric concept that likely will become synonymous with the network itself. We argue that reciprocal design of the network and applications will open new opportunities for the deployment of Metaverse-suggestive experiences even today.

2 CONCEPT

Experientially, this Metaverse is an extension of the Web into immersive XR modalities that are often aligned with physical space, as in augmented reality (AR). We conceive the Metaverse not only as a shared XR environment, but the next generation of the web, extending into 3D interaction/immersion and optionally overlaid on physical spaces. Instead of rendering data objects into a 2D page (within a tab within a window) on a device, we envision such objects being rendered into a shared 3D space, interacting among each other and with end users. Architecturally, leveraging ICN concepts provides support for decentralized publishing, content interoperability and co-existence, based on general building blocks and not within separated application silos as today's initial prototypes. We claim that such properties are required to achieve the generally circulated visions of Metaverse systems, but are not achievable

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today because of the host- and connection-centric way in which the web operates and is presented to users in browsers. We point out four ICN capabilities critical to Metaverse concepts: i) scalable and robust multi-destination communication, overcoming IP multicast challenges [8], such as inter-domain routing, scalability, and routing communication overhead; ii) leveraging wireless broadcast to support shared local views and low-latency interactivity without application-awareness in edge routers; iii) privacy, selective attention, content filtering, and autonomous interactions, as well as ownership and control on the publishing side; and iv) supporting in-network processing for objects replication and transformation.

For example, imagine *interactive holographic communication* consisting of participants' 3D video, spatial audio, and shared 3D documents. In ICN, such an application can represent virtual content as secure data objects and share them efficiently in a larger group of peers, fetching only the data necessary to reconstruct a suitable representation while being aware of the constraints of user devices and access networks. Furthermore, while experiencing 3D objects shared by the group, each participant may also interact in the same XR environment with personal services such as wayfinding, messaging, and *Internet of Things* (IoT) device status. Interactions between private and shared 3D objects would be simplified if these objects use similar conventions but with different security. This concept is semantically well-aligned with ICN properties, particularly for security, as it revolves around object-level data exchange rather than hosts or channels. Integration and interoperability within a shared XR environment, without centralization, is challenging if one has to negotiate not only data interactions but also the underlying service connections and security relationship using host-centric paradigms. It also exacerbates the impact of intermittent connectivity on interactivity when the global network is required for functions such as rendezvous – that are handled locally in ICN.

As a second example, consider *creating a shared environment* – e.g., to pre-visualize engineering models of an aircraft – from a collection of collaboratively edited 3D documents. Imagine component documents interacting in a simulation. Documents can be modularized, linked, and overlaid in a web-like manner. Today, such cross-platform interoperability and visualization without centralized hubs is impractical [12], and it is difficult to create secure, granular data flows required for interaction between co-existing 3D elements to "bring them to life" in a virtual world. In an ICN approach, such modules could be independently authored and published, shared between applications, becoming building blocks of a richer, *interacting* system of user- and machine-generated content.

3 TECHNICAL CHALLENGES

Many applications already employ data-oriented paradigms. Mapping them to a host-centric network model creates complexities and robustness issues that can be addressed with using a native ICN approach. While ICN benefits and deployment challenges have been discussed extensively in the literature, we focus on the unique research challenges and opportunities for ICN to be the underlying fabric of a web-like Metaverse. Two key examples: i) Approaches to "interconnect" virtual objects and systems published by different owners. For instance, implementing pouring a virtual cup of tea from a kettle owned by one user (and service) into another user's cup (hosted by another service) [11]; and ii) ICN versions of emerging XR object and communication standards, e.g., *Universal Scene Description* (USD) [9] and glTF [13]: ICN can be used for consistent and efficient sharing of scene and model descriptions. In addition, these and other key application-layer XR data structures are based on object hierarchies. Such documents can be hyper-media objects linking multiple components into a large context. ICN can make this a natural approach, operating on a fine-grained basis. Research is also required on communication and security paradigms, in particular for mutable versions of these objects.

Low-latency exchange of arbitrary objects and data streams is a fundamental enabler for Metaverse applications. This represents a challenge for current CDN-based infrastructures based on HTTP services such as DASH-based video on-demand streaming. For interactive multimedia, WebRTC protocols are more suitable, but they shift significant complexity to applications and do not provide a cross-application way to exchange data objects. A transition from the abstraction of "streaming" to selectively shared state may be much more suitable for Metaverse applications and is potentially well supported by distributed dataset synchronization techniques in ICN [7]. Current overlay approaches, such Media over QUIC (MoQ) [4] and extensions such as QuicR [5], blend real-time interactive media with streaming, albeit with some complexity.

What is needed is a fine-grained, hierarchical media exchange for low-latency interactive communication that enables scalable multi-destination distribution and in-network replication and transformation that **exposes application object hierarchy for fine-grained retrieval and security.** To support denser, large-scale communication sessions, such a service should be able to seamlessly leverage wireless broadcast. It must also provide support for heterogeneous devices and edge networks, i.e., providing only data elements needed for rendering, at different quality layers, possibly leveraging dynamic transcoding and level-of-detail support. With respect to low-latency and QoS in ICN, we suggest further research and experiments on **fine-tuning interest aggregation, caching and its influence on receiver-based performance estimation**, and the development of **specific QoS mechanisms** [10] to prioritize critical requests, such as prioritizing interaction data and baseline-quality media objects over higher quality objects. The fine-granular distribution, on-demand creation, and sharing of data objects in such systems calls for suitable security solutions that go beyond ICN's current object signing and encryption mechanisms. NDN Trust Schemas [14] demonstrated automated fine-granular authorization. In addition, mechanisms such as **provenance verification for data transformation** and UI support for **visualizing and authenticity and provenance** are needed as well.

In conclusion, we encourage consideration of the close relationship between the end-user experience of a Metaverse and an ICN architecture. An information-centric Metaverse could not only enable interoperable communication and data sharing, but also become the lingua franca for internal object representation and composition in platforms such as 3D game engines, similar to current Internet building blocks such as TCP, HTTP, and DNS that are used within application frameworks and microservice platforms.

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