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Approaching 6G Use Case Requirements with Multicasting

Nadezhda Chukhno, Olga Chukhno, Sara Pizzi, Antonella Molinaro, Antonio Iera, Giuseppe Araniti

***Abstract*—The shift towards 6G networks is expected to be accompanied by an increased capability to support group-oriented services, such as extended reality and holographic communications, in many different contexts, from high-precision manufacturing to healthcare and remote control. This range of applications will rely heavily on multicast and mixed multicast-broadcast delivery modes. This article focuses on the technological perspectives of 6G multicasting, highlighting requirements, challenges, and enabling solutions. We then run a simulation campaign to test practical solutions and draw conclusive remarks for forthcoming 6G multicast systems.**

I. Introduction

Rapid advances in sensing and imaging devices, low-power specialized processors, and display technologies are steering in a new era, wherein devices will be fused with human senses, thus shifting from a smartphone-based to a wearable-oriented paradigm. Besides, while virtual worlds continue to increase in fidelity, the mentioned advanced equipment would capture our life experiences and physical spaces. When combined with the need to offload and distribute computation due to the resource-constrained nature of miniaturized wearable devices, these advancements highlight the need for wireless network solutions with a level of performance not available in the fifth-generation (5G) yet [1].

The transition from the current 5G to sixth-generation (6G) system shall, therefore, go through the ability to support new classes of services. Some of them have already been identified, such as mobile broadband reliable low latency communication (MBRLLC), combining the requirements of 5G ultra-reliable low-latency and mobile broadband communications as well as mobility management at extremely high frequency (EHF) [2]. To support such services, simply exploring high-frequency channels to increase capacity is an insufficient measure to meet the 6G ambitions. Rather, the 6G wireless ecosystem advocates for the transition from a radio-centric system architecture to end-to-end converged communication, computing, control, localization, and sensing solutions, possibly enhanced by artificial intelligence (AI)-driven platforms.

This complex scenario is characterized by new disruptive applications and technological advancements, coupled to a growing importance of users acting as prosumers. Thus, new service delivery methods, not only based on traditional unicast communications but also on multicast and mixed-mode traffic delivery, will play a fundamental role [3]. For example, in case large groups of users request the same content, multicast-aided transmissions represent an efficient means to satisfy the stringent requirements of the mentioned MBRLLC applications. Despite this, mobility management at the EHF band for multicast service delivery is a challenging task since the antennas' beams should cover a group of moving users, which still requires the study of adequate technological solutions.

Besides the advanced features required by 6G applications, such as extreme capacity and ultra-high mobility for group-oriented applications and services, future 6G delivery networks must be flexible to meet the expectations of network operators, service providers, and customers. Delivering broadband connectivity in an efficient, cost-effective, and scalable way would seem to be possible only with *integrated broadcast and multicast systems*. Indeed, the complementary coverage of high-power high-tower broadcast networks and low-power low-tower cellular networks would better fulfill the demands of future 6G users, resulting in more efficient infrastructure utilization. This implies that 6G multicasting will need a more holistic framework for satisfying future communication needs than similar previous-generation platforms.

The goal of this work is to focus on the technological aspects of next-generation group-oriented services with keen attention to the role of multicasting and its integration with various approaches and technologies typical of 6G networks. Major contributions of the article include: *(i)* a concise historical overview of the development of multicast services and standards in cellular systems; *(ii)* a comprehensive taxonomy of 6G multicast use cases and their requirements, extending a classification from the literature; *(iii)* the identification of challenges and potential solutions for 6G multicasting; *(iv)* a feasibility analysis of the use of a set of the identified 6G enabling technologies for the provision of multicast services.

II. Multicast/Broadcast Services in Cellular Systems

Broadcast/multicast communications are considered the open door to resource-efficient transmissions when several users request the same data. To take advantage of this capability, the long term evolution (LTE) standards developed by the 3GPP included features to enable broadcasting, resulting in the design of the evolved multimedia broadcast and multicast service (eMBMS) architecture in LTE Rel. 9–12. Despite 3GPP's efforts to overcome eMBMS limitations in later releases, service providers have not adopted the technology widely.

5G did not support multicast/broadcast services in the first and second phases (Rel. 15 and 16). Then, to handle additional service types and fulfill the relevant quality of service (QoS) levels, 3GPP defined multicast broadcast service (MBS) for 5G new radio (NR) systems in Rel. 17, allowing the broadcast transmission to users in all radio resource control (RRC) states

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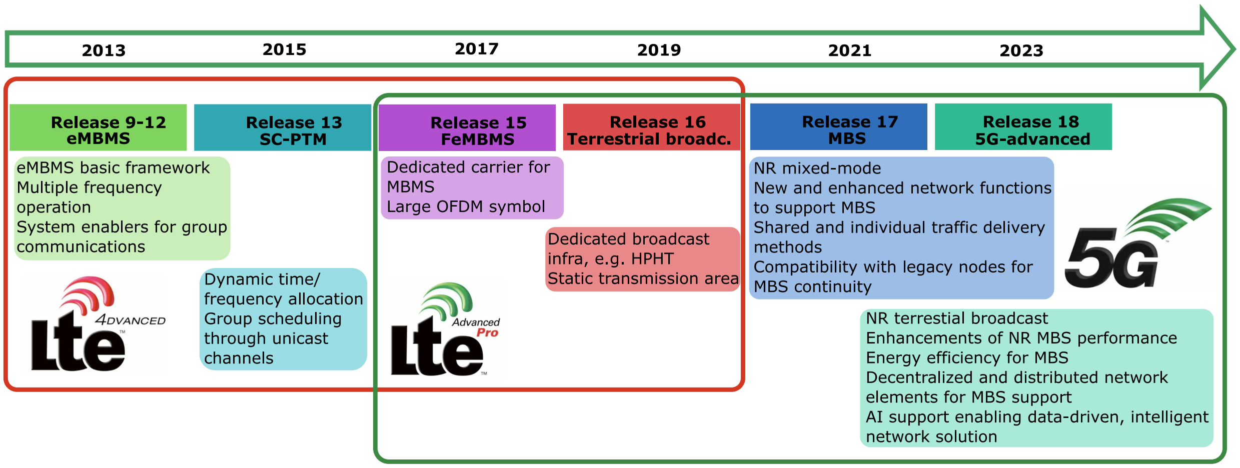

Fig. 1: Multicast/broadcast services evolution.

(both connected and idle) and multicast transmissions to users in the connected RRC state [4]. The basis for this communication mode is single-cell point-to-multipoint (SC-PTM) transmission, where multiple users receive a single physical channel within one cell.

In the future 3GPP Rel. 18, the 5G mixed-mode multicast will be enhanced to allow receiving broadcast and unicast services simultaneously in RRC connected states, the multicast capability will be extended to users in RRC inactive states, and research ways to increase resource efficiency in radio access network (RAN) sharing scenarios will be designed.

Although multicast/broadcast services should evolve in line with 5G standards, they pose specific challenges for 5G MBS. Mission-critical delay-sensitive signaling and high-resolution IPTV are two examples of newly emerging multicast services in MBS that demand the same levels of high reliability and low latency as unicast services, thus likely causing network congestion if not properly managed. As a result, a complex protocol stack design is required to reinforce reliability, latency, and service continuity.

In more-demanding 6G systems, supporting diversified transmission modes becomes mandatory, especially considering the requirements of high-bandwidth applications, for which multicast/broadcast transmissions shall be incorporated. This will enable a flexible, cost-effective, and scalable service delivery, which is especially beneficial when beamforming and resource capabilities of the base stations (BSs) are insufficient to serve all users in unicast mode. Broadband and broadcast/multicast convergence may be considered as a viable but practicable approach for achieving efficient and flexible resource management with 6G services.

Fig. 1 depicts the evolution in the standardization of multicast/broadcast services.

III. 6G Multicasting Use Cases and Requirements

Multicast communication can play a key role in improving efficiency and reducing network delay and load by allowing multiple users to receive the same content simultaneously, thus reducing the overall demand for network resources. Furthermore, multicasting can also improve the reliability of these services by reducing the impact of network congestion and failures.

In this section, we revisit the three-group classification of 6G use cases proposed in [2], with a special focus on the role of multicasting in terms of both possibilities it offers and requirements it poses. Table I summarizes the main points discussed in the remainder of the section.

Experience Sharing

The experience sharing use case includes applications that demand very high reliability and data rate as well as close-to-zero latency. Among these, 4K/8K high-definition (HD) video streaming, extended reality (XR), and holographic communications emerge for their special relevance. Indeed, high-resolution XR will have various applications, including video/TV broadcasting, manufacturing, automotive, workspace communications, education, entertainment, and eHealth. Despite the more stringent requirements of networked XR compared to 4K/8K video streaming, conventional resource allocation approaches treat all video traffic in the same manner, leading to an unacceptable delay in real-time UltraHD video streaming.

Alongside holographic communications, fifth dimension (5D) services integrating five human senses are projected to emerge in future 6G networks. However, their use of multiple-view cameras necessitates data rates of terabits per second, which cannot be handled by 5G.

In such a bandwidth-demanding scenario, especially in a dense user deployment, multicast traffic delivery can bring significant benefits to both communication and computing components. Specifically, the rendered frames of the complete third dimension (3D) hologram might be streamed to multiple users via multicast links to reduce total network latency and increase throughput, as unicast transmissions would be unbearable for the network to handle. Moreover, in the case of XR, the convergence of the standalone 5G NR broadcasting/multicasting, 5G service-enabled core networks, and non-3GPP dual connections can ensure delivering XR video with remarkable automation, service quality, and stability [5].

TABLE I: 6G Use Cases Requirements [1], [2].

Use Case	Latency	Throughput	Reliability	Mobility Support	Multicast Features
Experience sharing					
4K/8K HD	15-35 ms	35-140 Mbps	-	✓	↓ latency, ↑ stability
XR	5-7 ms	25 Mbps-5Gbps	99.99999%	✓	↑ stability, ↑ service quality, ↓ latency
Holographic	sub-ms	4-10 Tbps	-	✓	↓ latency, ↑ throughput
Remote control and robotic technology					
eHealth/remote surgery	sub-ms	-	99.99999%	✓	↓ latency, ↓ congestion
Industrial automation	0.1-1 ms	Gbps order	99.9999999%	✓	↓ latency, ↓ congestion, ↓ energy and resource usage, ↓ jitter
Autonomous mobility	< 1 ms	-	99.99999%	✓	↓ latency, ↓ congestion
Connected everything					
Ubiquitous connectivity	-	1 Gbps	-	✓	↑ freshness of data
General use case					
6G	0.1 ms	1 Tbps	99.9999999%	✓	↓ latency, ↓ congestion
5G	1 ms	20 Gbps	99.999%	-	↓ latency, ↓ congestion

Remote Control and Robotic Technology

This use case encompasses eHealth, remote surgery, industrial automation, and autonomous mobility verticals and exploits both robotic technology and wireless networking to connect users who are geographically distant. Powerful XR and holographic tools, computers, and methods are required to adjust to human senses and physiology. Examples of industry automation use cases are high-precision manufacturing, real-time operations with microsecond jitter, autonomous systems, and wireless brain-machine interactions.

Within this category of use cases, multicasting can be used to upgrade the software of a collection of internet of things (IoT) devices or switch on a set of street lights at once. Additionally, the majority of industrial applications use multicasting for system control [6], where deterministic latency and jitter are needed to achieve real-time control. Compared to multiple unicast transmissions, multicasting in this situation results in more effective bandwidth utilization, reduced delay, and improved energy and resource utilization since data are sent only once for all devices.

Connected Everything

Personal gadgets, XR equipment, sensors, cars, and other device types will be connected through 6G networks stimulating the need for "anything, anytime, anywhere" communications. This would put further strain on already overburdened 5G networks, which will be unable to offer connectivity to all devices while satisfying the services' requirements. Furthermore, to allow scalable low-cost deployments with little environmental impact, 6G networks would require a total energy efficiency of 10–100 times higher than in 5G.

Environmental sensor networks and networks of self-driving cars have generated many applications demanding real-time information updates, thanks to recent improvements in pervasive connection and ubiquitous computing. The freshness of the data at the interested receivers must be improved in all of these applications.

Group-based interactions are prominent in many pervasive computing scenarios due to their intrinsic user-centric nature and group interaction capabilities. For example, for time-sensitive data gathering and monitoring systems consisting of multiple recipients, sending update messages through multicast or broadcast channels can minimize the age of information (i.e., improve freshness) at each receiver and save bandwidth.

IV. Challenges

This section discusses the gaps between requirements and current possibilities for realizing 6G multicasting use cases.

Ensuring QoE

6G lays special focus on user's quality of experience (QoE) rather than QoS, thus targeting user satisfaction rather than network-centric optimization. Most 6G applications require a high data throughput with negligible latency, which is essential, e.g., for XR applications, since a delay surpassing the one indicated in Table I will cause the users to feel dizziness. The target 6G latency requirement of < 1 ms is very challenging to achieve. This issue must be addressed at both the physical and networking levels. Furthermore, 6G requires extremely reliable low latency communication (ERLLC) to offer 99.99999999% reliability for heterogeneous devices across both the uplink and downlink.

However, *QoE for multicast transmissions is even more challenging with respect to unicast traffic delivery* due to the higher probability of throughput performance deterioration caused by the data rate limitation imposed by the group member in the worst channel conditions. In practice, more radio resources should be allocated to the users with low channel quality indicators (CQIs) to achieve a high transmission rate and, hence, low latency. This can result in higher network resource usage and QoE degradation of the whole multicast group. The balance between allocating more resources to low CQI multicast groups and degrading other groups' QoE can be achieved, for example, by creating larger multicast groups. This can lead, on the one hand, to more efficient use of resources due to fewer sequential transmissions required. On the other hand, large multicast groups likely require the use of wider beams, which can negatively affect the performance of mmWave systems. Evidently, QoE-based 6G networks require careful multicasting implementation.

Utilizing THz Frequency Range

6G applications have triggered the demand for the exploitation of higher frequencies. The question of whether the propagation channel model can be unified throughout the entire frequency range from gigahertz (GHz) to terahertz (THz) remains unanswered. In the millimeter wave (mmWave) bands, obstacles can attenuate the propagation paths over which significantly more power is delivered to the target user than in systems operating at lower frequencies. Also, the signals suffer from diffraction and diffuse scattering, contributing to a sparse propagation environment. In the sub-THz spectrum, this may be even slightly magnified. However, there are some robust specular contributions, which result in a few propagation clusters and significant delay and angular spreading. Highly-directive antennas increase channel sparsity even further, compensating for higher global path loss at sub-THz frequencies.

Multicast mode poses unique challenges as group members are likely to be close together, meaning a user could obstruct the line-of-sight (LoS) path on which THz communications rely. This causes a deterioration in channel condition for all multicast group members as group performance is limited by the user under the worst channel conditions. Therefore, THz signals for multicasting are even more sensitive to blocking and require mechanisms to efficiently cope with different and dynamic adverse channel conditions.

Supporting Mobility

Supporting mobility at high-frequencies is a critical challenge. Directionality is necessary to achieve an adequate link budget to sustain high-capacity connections. Nevertheless, beamforming and precise beam alignment have serious implications for the design of control tasks, including user/group tracking, handover, and radio link failure recovery.

For networks with high-speed nodes, the management of *large-scale mobility* calls for effective beam switching and beam tracking functions to ensure uninterrupted communication. *In the case of group mobility, the beam should track the major part of the multicast group users, which is more challenging since users may follow different mobility patterns.*

Users of XR applications are regarded to be dynamic also in terms of *small-scale mobility*. Arm movement, body pivot movement, head rotations, nutation, and bending knees to full and semi-squat positions are all examples of their dynamicity. Due to the strong directionality of transmissions, even minor movements may cause blockage or frequent misalignments, leading to the spontaneous signal-to-noise ratio (SNR) degradation and waste of communication time for the beam searching procedure.

In the case of multicasting, the blocked user deteriorates the user-perceived throughput performance of the whole group. While mobility in directional multicast systems has only been partially addressed in 5G due to less stringent service requirements, 6G needs to include *mechanisms to handle group mobility in highly directional networks*. Indeed, 6G will require new physical layer techniques capable of providing robust broadband connectivity in high mobility scenarios to ensure the reliability of multicast services. Therefore, more efficient multicast implementations are needed, the main ones being discussed in the next section.

V. Enabling Solutions

This section presents potential solutions, summarized in Table II, to overcome the challenges of 6G applications employing multicasting.

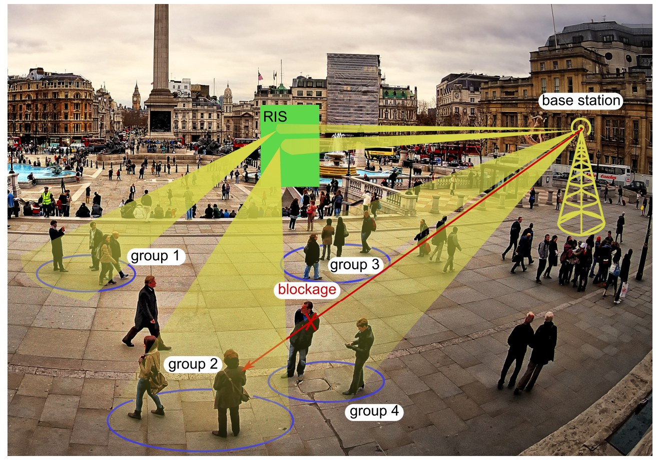

Fig. 2: RIS-aided multicast systems.

Integrated Broadcast-Multicast-Unicast Communications

The 6G architecture should enable flexible and on-demand integration of broadcast, multicast, and unicast to provide a reliable service. For example, when a multicast group member moves far from the group or obstructs its transmission path, the system should be able to exclude such a user from the multicast group and smoothly switch the transmission mode to unicast or broadcast. Thus, in case of chaotic behavior of many users in the group, the system should be able to make intelligent, real-time decisions on the mode of transmission based on user needs and content characterization.

RIS-based Multicasting

The opportunities given by the utilization of the THz and sub-THz spectrum come with many challenges. While the high free-space path loss of THz systems presents a challenge, the THz radio spectrum includes favorable windows between atmospheric absorption peaks above 500 GHz. In addition to these boundaries, penetration and reflections from various materials are critical components to be considered.

To mitigate these drawbacks, reconfigurable intelligent surfaces (RISs) can provide virtual LoS paths by adjusting the phase shifts, which can address mobility issues and improve multicasting performance by dealing with the known group data rate limitation imposed by the user with the poorest channel condition (see Fig. 2). However, multicast rate rapidly saturates as the phase shift number grows, decreasing with the number of users. Furthermore, multicast data rates can be considerably improved by deploying a large number of RF chains or reflecting elements. Even if it is generally better to provide users in poor channel conditions with more power, with large pilot power or massive reflecting elements, equal power allocation is preferable [7]. Nevertheless, the design of optimized multicast beamformers may require solving complex optimization problems. Thus, the complexity needs to be reduced, e.g., by adjusting the multiplexing gain to the problem size.

TABLE II: Challenges and enabling solutions.

Challenges	Solutions
Ensuring QoE	RIS-based multicasting (throughput/multicasting rate)
	Mobile edge multicasting (latency, bandwidth)
	Joint multicasting/coded caching, PDA (high-rate low-latency traffic)
	ML and AI (latency-critical applications)
	(Multicast) cell-free MIMO networks
	Heterogeneous TN/NTN architecture in the delivery of multicast services + softwarization and virtualization technologies
Utilizing THz frequency range	(Multicast) cell-free MIMO networks
	RIS-based multicasting (by avoiding non-line-of-sight (nLoS))
Supporting large-scale mobility	(Multicast) cell-free MIMO networks and smart surfaces
	RIS-based multicasting (by avoiding nLoS)
	Mobile edge multicasting
	Space-terrestrial integrated multicast network by offering backhaul assistance
	Integrated broadcast and multicast networks (flexible and adaptive delivery)
Supporting small-scale mobility	RIS-based multicasting (by avoiding nLoS)
	Integrated broadcast and multicast networks (flexible and adaptive delivery)
	Mobile edge multicasting

Multi-group Multicast Cell-Free Massive MIMO

Cell-free massive multiple-input and multiple-output (MIMO) systems, in which a large number of geographically distributed access points (APs) synchronously and coherently serve a small number of users in the same time-frequency resource, have revealed unprecedented levels of macro-diversity, spatial multiplexing, and macroscopic diversity gains, by leveraging signal co-processing at all APs.

Cell-free network operations will provide seamless mobility support with no handover overhead, which might be frequent when considering THz frequency systems. They will ensure QoS in accordance with the most demanding mobility requirements anticipated for 6G applications. For mobile and stationary access, cell-free smart surfaces at high frequency supported by mmWave tiny cells can be considered.

Further, as stated in [8], exploring the potential performance advantages provided by the latent marriage of cell-free massive MIMO, low-resolution analog-to-digital converters/digital-to-analog converters, and multigroup multicast technologies is crucial. Moreover, it is urgent to consider the effects of both single- and multi-antenna users, such as laptops, tablets, and smart vehicles, helping improve the QoE level.

Mobile Edge and Multicasting

The network architecture must be adaptable to support a broad range of network components and processing instances deployments, each suited to the specific use cases' demands and leveraging their unique requirements. Both the deployment of applications at the network edge and new network application interactions are expected to be critical in enabling optimized QoE performance in terms of latency and bandwidth as part of the network customization to different use cases.

Integration of mobile edge computing (MEC) with multicasting has become a logical alternative for bandwidth offloading in both radio access and backhaul networks [9]. The advantage of using MEC is that it improves multicasting reliability over the core network and optimizes multicast video streaming over the NR MBS. The MEC server may also communicate with moving devices using a wireless multicast channel, thereby providing significant bandwidth savings.

Joint Multicasting / Coded Caching

In novel coded caching techniques, contents are distributed among several cache memories throughout the network, as opposed to simply replicating highly-popular information close to (or at) end-users. Coded caching operates in two phases – placement and delivery. During placement, content files are split into smaller parts stored at different cache memories. During delivery, several codewords are built after users disclose their requests, and each codeword is multicasted to a subset of target users. Placement and delivery phases aim to ensure that, after multicasting each codeword, every target user can eliminate undesired terms from the received signal using its cache contents and obtain (parts of) its requested data interference-free.

Coding multicast opportunities can also be a means to reduce the required uplink and downlink transmission bandwidth. The placement delivery array (PDA) technique [10] gained a lot of attention in this evolving field. A PDA can indicate what users should cache and what should be sent from the server in a single array. Coded caching and PDA can facilitate high-rate low-latency communications and improve users' QoE, e.g., in multi-user XR. However, PDA design has high computational complexity.

AI for Multi-User Latency-Critical Application

Leveraging AI technology, such as deep learning and neural networks, can reduce the end-to-end latency of 6G applications by predicting user requests and channel state changes. This allows to effectively allocate caching and processing resources in a multi-user XR scenario [11].

Machine learning (ML) techniques can complement the traditional model-driven algorithmic design with data-driven approaches. When the underlying models are accurate, the traditional model-driven method works well. A potential benefit of applying ML comes when a channel modeling deficiency occurs, and the propagation environment is not straightforward (as in the case of multicasting), defined by distinct but unknown parameters. Further, under particular situations, the data-driven approaches may lead to high algorithm complexity in terms of computation, run-time, and acquiring the necessary side information. This algorithmic deficiency might be potentially ameliorated by ML techniques that can learn how to take shortcuts in the algorithmic design. This is especially critical when guaranteeing effective signal processing for latency-critical multicast applications and jointly optimizing many blocks in a communication system.

Space-Terrestrial Integrated Multicast Network

To realize a fully connected digital world, 6G will need to integrate terrestrial networks (TNs) and non-terrestrial networks (NTNs) into a unified wireless system. Drones can be used to supplement terrestrial networks by connecting hotspots and infrastructure-limited areas. Meanwhile, low-orbit satellites (LEOs) and CubeSats may offer backhaul assistance and extra wide-area coverage for both drones and terrestrial BSs.

Furthermore, broadband satellite networks have the capability of distributing multimedia content worldwide in a scalable, flexible, and efficient way by means of multicasting. However, existing research has mainly focused on IP multicast for the satellite environment, which has limited scalability. Softwareization and virtualization technologies can be employed in heterogeneous TN/NTN architectures providing multicast services to efficiently manage network resources in real time [12].

VI. Case Study

In this section, we validate the feasibility of employing a set of the 6G enabling technologies discussed in the previous section for multicast service delivery. Specifically, we evaluate the performance of multicasting that leverages EHF communications coupled with AI/ML and passive RISs with a different number of reflective elements. Also, since video streaming is very computationally intensive, we consider the possibility to upload the task to the edge for processing.

In detail, we consider XR video streaming as a reference 6G multicast application, and evaluate the following system settings: *(i)* traditional video streaming using a mobile phone; *(ii)* XR video streaming using a head-mounted display (HMD); *(iii)* XR video streaming using an HMD exploiting one RIS with 1024 and 2048 reflective elements; and *(iv)* XR video streaming using an HMD exploiting one RIS with 1024 and 2048 reflective elements and an AI/ML-based algorithm enabling motion prediction (up to 80 ms [13]).

For the video frame rendering, we use measurements based on the Huawei 5G network XR test with edge/cloud services [13]. We simulate parallel computing on the edge server with a degradation factor of 0.02. The time between requests is set to 11 ms (for frame rate 60 fps). The size of the uncompressed video frame to be downloaded is 63.7 Gb (i.e., 8K resolution, 8-bit color depth) with a compression rate of $150 : 1$. The uplink enables a data rate of 150 kbps for motion data.

Ten multicast groups of up to 4 users are formed using a hierarchical clustering strategy implementing a ward linkage function tending to produce compact groups of well-distributed size. We simulate a multicast session implementing interactive on-demand video with a data rate of 25 Mbps following [14]. Since the analysis is focused on multicasting, we do not consider the presence of unicast traffic.

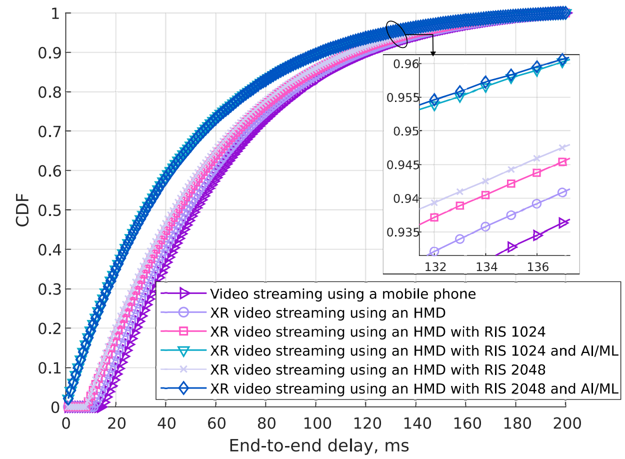

Fig. 3: CDF of end-to-end delay.

We simulate pedestrian mobility based on a social force model to imitate real-life user behavior. As a baseline model, we assume an average motion with the speed of 3 km/h using a mobile phone. Users in HMDs move with -46% deviation in speed compared to baseline [15]. We consider the 3GPP channel model in an urban micro (UMi) environment with mmWave frequency band at 28 GHz and μWave (sub-6 GHz) band at 3.5 GHz for downlink and uplink, respectively. The transmit power and the operating bandwidth at uplink and downlink are 10 dBm @ 100 MHz and 33 dBm @ 400 MHz, respectively. Users are connected to 4 mmWave/μWave BSs, each co-located with an edge computing server.

We assess the system performance with different settings in terms of end-to-end delay and ratio of reliably delivered packets. Uplink transmission, processing on edge, migration between edge servers, and downlink transmission delays make up the end-to-end delay. Encoding/decoding-related procedures are not considered in this study. We disregard RIS processing delay, which is negligible for passive RISs, and expect that our analysis remains valid also when considering it.

Fig. 3 shows the CDF of the end-to-end delay for all the schemes under analysis. First, we learn that system-level performance characterization of XR and traditional mobile phone applications differ substantially. The observed gap between XR and mobile broadband applications is due to differentiation in motion patterns (which affects connectivity schemes) and channel conditions (which vary according to, for example, equipment elevation). The gap becomes more tangible when having RIS-assisted transmissions. As expected, the more RIS reflective elements, the better the system performance due to the better propagation environment. Finally, ML/AI technologies implemented for motion predictions allow rendering video frames in advance (i.e., proactive approach), reducing the delay and satisfying 6G requirements.

Fig. 4 illustrates the system behavior in terms of the percentage of successful transmissions within a given SNR threshold. Results highlight that RISs of smaller size fail to handle highly blocked paths. Indeed, starting from a blockage probability of

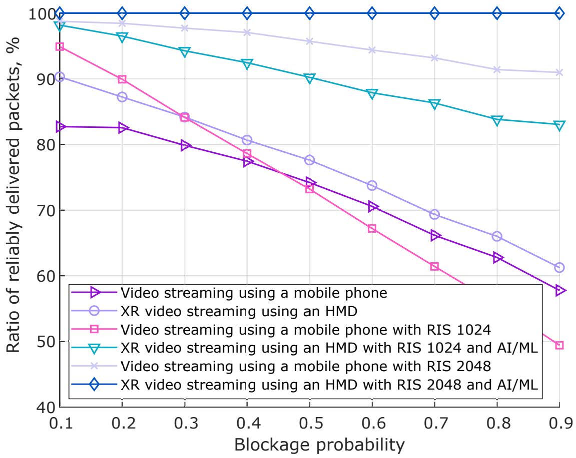

Fig. 4: Ratio of reliably delivered packets under increasing blockage probability.

0.3, the usage of RIS does not bring benefits w.r.t. RIS-less transmission. However, AI/ML tools may fully compensate for this unsatisfactory behavior in highly blocked regions in case of both 1024 (to some extent) and 2048 elements. Additional results, not shown due to space constraints, underline that installing a single RIS of sufficient size close to the BS is more advantageous than installing RIS close to multicast users/groups, especially in cases of high mobility and density of users.

VII. Conclusive Remarks

Group-oriented services are going to become a leading technology to cater to the 6G application requirements that go far beyond mobile Internet usage. As our study conclusively reveals, 6G applications will benefit from multicast operation to cope with strict requirements by reducing latency, improving throughput, enhancing reliability, and traffic congestion. In this study, we investigated the holistic 6G multicasting framework focusing on the technological perspectives. We revealed the role of multicasting in future 6G systems along with the complementing approaches and technologies, their requirements, challenges, and solutions. We then demonstrated the identified solutions' applicability to cope with 6G multicasting challenges.

Acknowledgment

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