Performance Evaluation of Extended Reality Applications in 5G NR System

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***Abstract*—We present system-level evaluation results to characterize the performance of eXtended Reality (XR) applications over a 5G NR system. A split-rendering framework is assumed, where the XR device uses 5G to offload computation associated with rendering and encoding of video frames to an edge server. The XR traffic model includes rendered video frames on the downlink and user pose and control updates on the uplink. We present results for both sub-6 GHz (FR1) and millimeter-wave (FR2) bands. Additionally, we also discuss potential enhancements to further improve user experience for XR applications over 5G.**

Keywords—Network coding, Interference coordination, Forward error correction, Delay-aware scheduling

I. Introduction

Extended reality (XR) is emerging as a key application of 5G NR systems. The term XR covers a broad range of use cases such as virtual reality, augmented reality, cloud gaming and conferencing. The requirements depend on the specific use case [1], but a common theme across all the use cases is that XR combines the requirements of high throughput and low latency. Additionally, power consumption considerations are also very important.

This paper aims to evaluate the performance of XR applications over 5G NR using system-level simulations. In addition to characterizing performance, the paper discusses several potential enhancements to 5G that could improve user experience.

The main contributions of this paper are as follows:

- We present system-level performance evaluation results for XR applications in a multi-cell 5G network using the channel modeling techniques, evaluation methodology, and statistical traffic model agreed in 3GPP. We present results for sub-6 GHz and millimeter-wave systems for downlink and uplink scenarios.
- We propose several enhancements to 5G to better support XR application requirements, including techniques such as traffic-awareness in the RAN, interference coordination, network coding, semi-persistent scheduling and mobility-related enhancements.
- We present simulation results to quantify the potential performance gains for some of the proposed enhancements.

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II. Evaluation Methodology

A. System Model

In this study, we assume a split-rendering framework as described in [1]. In our model, an XR device offloads rendering and encoding computation to an edge server across a 5G link. This approach allows a significantly enhanced user experience with acceptable device power consumption. To enable this framework, the XR device conveys user pose and other control information over the uplink and the server sends the rendered and encoded frame over the downlink. An important requirement for good user experience is to minimize the motion-to-render-to-photon (M2R2P) delay, which is the end-to-end delay between when a user changes pose and when this gets reflected in the rendering and eventually in the displayed frames. The simulation model assumes a 5G cellular system with multiple base stations and multiple users randomly dropped within their area of coverage. Each user is assigned a traffic source that models the split-rendering framework. The XR performance is then evaluated as a function of network load.

B. Traffic Model

Table 1: Traffic Requirements and Parameters

Parameters	*Values (DL)*	*Values (UL)*
Traffic Type	Video	VR Pose updates
Periodicity	1/60fps (frame rate = 60fps)	4 ms
Packet Size	Truncated Gaussian distribution [STD, Max, Min]: [10.5,150, 50]% of mean packet size	100 bytes
PDB	VR/AR: 10ms; CG: 15 ms	10ms
PER/Target BLER	1% (PER)	10% (Target BLER for 1st Tx)
Jitter	Truncated Gaussian: Mean: 0 ms; STD 2 ms; Range [-4, 4] ms	No jitter

The traffic model assumed for this study is based on the 3GPP XR study item [2], [3]. Pose and control traffic on the uplink is modeled as a stream of packets, each 100 bytes in size, arriving every 4 milliseconds. Downlink traffic arrivals are periodic (based on the frame rate) with a random jitter model. The frame size follows a truncated Gaussian distribution. The details are discussed in Table 1. (Note: for downlink, the term "packet" in the simulation and in Table 1 corresponds to a unit of arrival representing a single video frame).

C. *Key Performance Indicators*

Each downlink frame and each uplink pose update has a delay budget. For each user, the key performance metric is the proportion of frames that are delivered on time. A user is declared to be satisfied if at least 99% of its frames (or pose updates for uplink) are successfully delivered within the delay budget.

III. Performance Results

A. *XR Performance Results With FR1 5G NR*

Table 2 presents the simulation assumptions for the FR1 (sub-6 GHz) scenario:

Table 2: FR1 Simulation Assumptions

BS Antennas (M, N, P, Mg, Ng; Mp, Np)	(8, 8, 2, 1, 1; 4, 8) with 64 TXRU
BS Antenna spacing	d_H= 0.5 λ, d_V= 0.5 λ
Carrier Frequency	4 GHz
System Bandwidth	100 MHz
Numerology	30 KHz SCS, 0.5 ms slot
UE PHY processing delay	Capability 1
gNB PHY processing delay	3 slots
UE Antennas (M, N, P, Mg, Ng; Mp, Np)	4 (1, 2, 2, 1, 1; 1, 2); d_H= 0.5 λ
Layout	200 m ISD, 21 cells (wraparound) Indoor UEs on multiple floors
Channel model	3D UMa (ISD 200m)
UE Distribution	80% indoor, 20% outdoor
BS electrical steering angle	102 degrees
Antenna gain per element	BS: 8 dBi; UE: 0 dBi
Noise Figure	BS: 5 dB, UE: 9 dB
gNB Max Power	44 dBm per 20 MHz
UE Max Power	23 dBm
Doppler	3 Kmph
TDD Config	DDDSU
Scheduler	MU-MIMO Proportional Fair
Guard Band Overhead	2.08% (272 RBs in 100 MHz)
Channel Estimation	Realistic

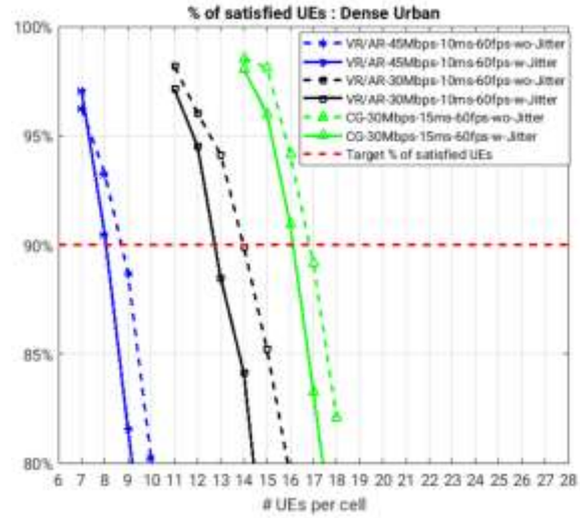

Fig. 1: DL performance: Dense Urban (FR1)

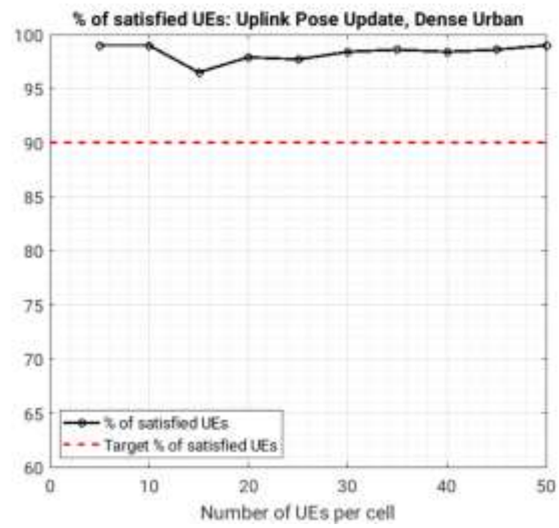

Fig. 2: UL performance: Dense Urban (FR1)

1) *Downlink*

Fig. 1 shows the trend of XR downlink performance in terms of the percentage of satisfied UEs as load increases, for different traffic models shown in Table 1. For virtual/augmented reality (VR/AR), the packet delay budget (PDB) is 10 ms, and for cloud gaming (CG) it is 15 ms.

2) *Uplink*

Fig. 2 shows the uplink performance for the pose and control traffic of a VR application. The results indicate that due to the low throughput requirement of the pose update traffic, the uplink is not the bottleneck in this case.

B. *XR Performance Results With FR2 5G NR*

In 5G NR, FR2 systems are deployed in the millimeter band which provides many benefits such as large system bandwidth operation and the opportunity to use a massive number of antennas which are both useful for applications demanding high date rates like XR. On the other hand, FR2 has inherent propagation challenges such as increased susceptibility to blocking. This issue is typically addressed by using techniques such as beamforming [4].

Table 3: System Simulation Parameters

Parameters	*Values*
Deployment	Indoor Hotspot
Layout	120m x 50m, ISD: 20m, TRP numbers: 12
# of UE per cell, N	DL/UL: 1 to 30
Channel Model	Indoor Hotspot
Carrier frequency	30 GHz
Subcarrier spacing	120 kHz
Scheduler	SU MIMO PF Scheduler
BS antenna pattern and gain	Ceiling-mount antenna radiation pattern, 5 dBi
BS Antenna Configuration	◦ 2 TxRU, ◦ (M, N, P, Mg, Ng; Mp, Np) = (16, 8, 2,1,1;1,1) ◦ (dH, dV) = (0.5, 0.5)λ
gNB Tx Power/EIRP	100 z: Tx = 24 dBm, EIRP = 50 dBm 400 MHz: Tx = 30 dBm, EIRP = 56 dBm
UE antenna pattern and gain	UE antenna radiation pattern model 1, 5 dBi
UE Antenna Configuration	(M, N, P) = (1, 4, 2), 3 panels (left, right, top), (Mp, Np) = (1,1)
UE Tx Power/EIRP	100 MHz: Tx = 23 dBm, EIRP = 34 dBm 400 MHz: Tx = 23 dBm, EIRP = 34 dBm

With the FR2 context in mind, we present VR capacity results based on a system simulation analysis of VR users in an Indoor Hotspot deployment [5]. In this setup, the VR users' devices in a cell are connected to the gNB using an FR2 link and there are ***N*** VR users in a cell. The DL and UL traffic and system simulation parameters used for this evaluation are based on parameters agreed upon in the 3GPP RAN1 XR Study Item with the important parameters presented in Table 1 and Table 3.

For both DL and UL evaluation results, we present the % of Satisfied UEs as a function of ***N*,** the number of UEs per cell for each simulation scenario. From these curves, we then evaluate the VR system capacity, where the system capacity is defined as the maximum number of users/UEs per cell with at least 90 % of users/UEs satisfying the application requirements (i.e. Packet Delay Budget (PDB) and Packet Error Rate (PER)).

1) Downlink

In Fig. 3, we present the % of satisfied UEs per cell versus the number of UEs per cell for VR application with bit rates of 45 Mbps and 30 Mbps and PDB = 10ms for the InH

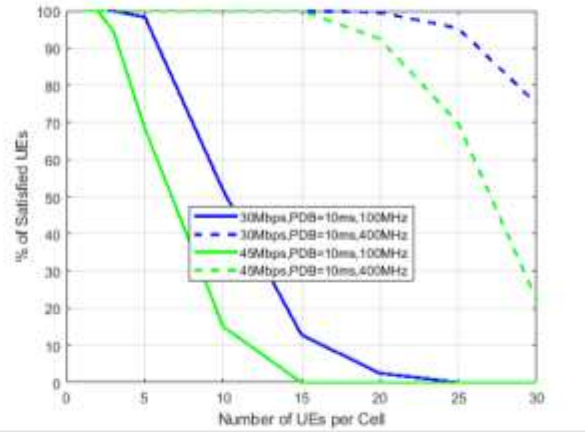

Fig. 3: Capacity for VR DL traffic

deployment. The TDD configuration of DDDSU is used for these evaluations.

The results illustrate a significant capacity improvement with bandwidth increase. Specifically, by comparing the 45 Mbps curves with bandwidths of 100 MHz and 400 MHz, a capacity increase from approximately **3** to **20.5** UEs can be observed. Similarly, comparing the 30 Mbps curves with bandwidths of 100 MHz and 400 MHz, we observe a capacity increase from approximately **5.5** to **26** UEs. These results indicate that by leveraging the large bandwidth opportunities offered by FR2, the DL capacity of the VR users in the 5G network can be significantly increased. Another noteworthy trend in these curves is the impact of the bit rate on the VR DL capacity. Based on the rendering parameters of the video in the VR application, the different bit rates may be used for rendering the downlink traffic. The results in Fig. 3 show that as the bitrate of the VR traffic decreases from 45 Mbps to 30 Mbps, the per UE demands on the system resources decreases leading to an increase in the % of users that are satisfied. Specifically, for the curves with 100 MHz bandwidth, by decreasing the VR bit rate from 45 Mbps to 30 Mbps, a capacity increase from 3 UEs to 5.5 UEs can be observed. For the 400 MHz bandwidth curves, by decreasing the bit rate from 45 Mbps to 30 Mbps, a capacity increase from 20.5 UEs to 26 UEs can be observed. These results indicate that decreasing the bit rate of the VR downlink traffic could lead to significant increase in the capacity of VR users, especially, at larger bandwidths.

2) Uplink

In Fig. 4, we present the % of satisfied UEs per cell versus the number of UEs per cell for VR application when the UE is transmitting pose updates with the parameters shown in Table 1. For this UL setup, when the gNB uses all its antenna and time multiplex users on a slot basis (as is traditionally done in 5G NR FR2 systems and also used in the DL results presented in Fig. 3), a capacity of **7** UEs can be observed for both 100 MHz and 400 MHz (as shown by the curves labelled "Full antenna, Regular slot"). These results show that unlike the DL, increasing the bandwidth does not increase capacity because the pose update packets are small (i.e. 100 bytes).

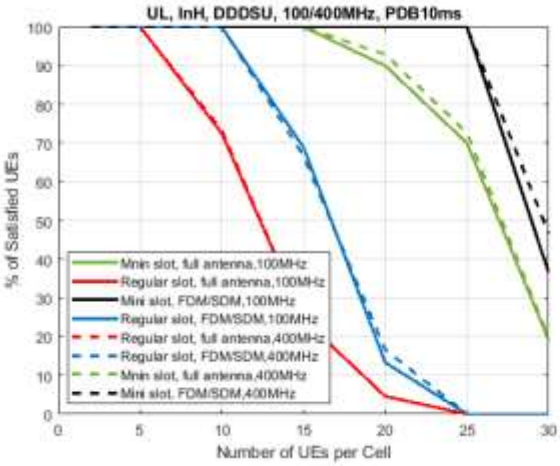

Fig. 5: Capacity for VR UL Traffic

Instead, the UL capacity bottleneck is caused by the number of users that can be time-multiplexed in the system.
For the 400 MHz results, when we compare the DL capacity of >20.5 UEs with the UL capacity of 7 UEs, the UL becomes a bottleneck. Therefore, to address this issue we explore 3 schemes that allow the gNB to multiplex more UEs in the time, frequency or spatial domains. These schemes are:

1. **FDM/SDM and Regular Slot:** The gNB equally divides its bandwidth (e.g. 100MHz or 400 MHz) and antennas into $\boldsymbol{M}$ groups (where $\boldsymbol{M = 4}$) and services the $\boldsymbol{M}$ groups of UEs simultaneously. This scheme is analogous to MU-MIMO with non-overlapping frequency resources. Users in a group are time-multiplexed on a slot basis.
2. **Full Antenna and Mini-slot:** This is the 3GPP 5G NR defined PUSCH Type B feature which is commonly known as "mini-slot" where the gNB time multiplexes multiple users within a slot by allocating $\boldsymbol{T}$ symbols to each UE. In this analysis, $\boldsymbol{T = 7}$ symbols which implies two users per slot are multiplexing onto an UL slot. The gNB uses all its antennas for receiving pose updates from a given user.
3. **FDM/SDM and Mini-slot:** In this scheme, the gNB support $\boldsymbol{M}$ groups of UEs simultaneously while using mini-slot to time -multiplex UEs within the same group.

When we apply the FDM/SDM with full antenna scheme which allows the gNB to support $\boldsymbol{M}$ simultaneous groups users in frequency and spatial domains per slot, we observe a capacity increase from **7** UEs (in the "Full antenna, regular slot" scheme) to **12** UEs indicating that multiplexing more users in the frequency and spatial domain improves the uplink capacity. Also, it is important to note that an $\boldsymbol{M}$ **factor** increase in capacity was not achieved partly due to reduction in the number of antennas used in each group which reduces the array gain. More capacity improvement is realized when the full antenna with mini-slot scheme is used; this scheme achieves a capacity of **20** users as result of time-multiplexing more users within a slot. The highest capacity increase (i.e. ability to support **26** users per cell) is achieved by combining the FDM/SDM with the mini-slot. This is a result of enabling user multiplexing in the frequency, spatial and time domains.

In summary, by leveraging schemes that enable user multiplexing in the time, frequency and spatial domains, the VR UL capacity can be significantly improved.

C. Frame Rates and FEC of Downlink Video Traffic

The frame rates and error correction coding of XR video traffic play an important role in the system performance. To achieve the high reliability requirement of DL video traffic, periodic video frames must be delivered within a period for queue stability. Otherwise, video frames will accumulate in the buffer and eventually miss the deadlines, resulting in loss of reliability and capacity. Fig. 5 shows that the effective downlink delay budget is capped by not only the latency requirement but the traffic periodicity, where one packet of the first frame will always miss the deadline after the period regardless of its delay budget set to 12 to 20 ms.
Given the effective delay budget is min(latency requirement, 1/fps), Table 4 shows how the DL system capacity scales with the latency requirement under different frame rates, where the capacity is defined as the maximum number of UEs per sector under which at least 90% of UEs meet QoS (simulation assumptions are given in Table 5). For the 90fps traffic, the capacity cannot scale with delay budget beyond the 11.1ms

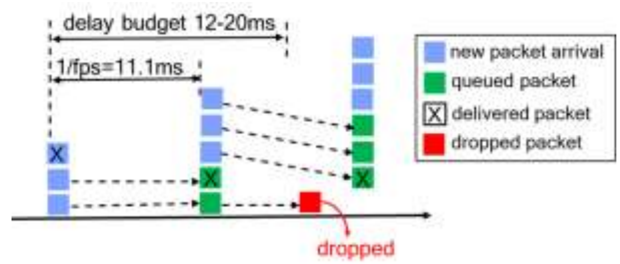

Fig. 4: A single-user example with 90 fps traffic and 3 packets per frame. At most one packet is delivered per period in this unstable system.

periodicity.

Table 4: Downlink capacity under (90fps, 50Mbps) and (60fps, 42Mbps) traffic with different delay budget.

DL delay budget	10ms	12ms	15ms	20ms
Capacity (90fps)	12 UEs/cell	12	12	12
Capacity (60fps)	14	18	18	18

Table 5: System-level simulation assumptions

Scenario	InH, one sector with 7m ISD
Carrier frequency	28GHz
SYS BW, SCS	100MHz, 120KHz
gNB antenna config	(M,N,P,Mp,Np)=(16,8,2,1,1)
UE antenna config	(M,N,P,Mp,Np)=(2,2,2,1,1)
gNB EIRP	30dBm
UE mobility	100% indoor with 3kmph
Modulation order	64QAM
Processing time	3GPP R15 capability 1
UE reliability QoS	70% (under 30% FEC)

Applying forward error correction (FEC) to video traffic is a useful feature to relax the XR reliability requirement at the cost of higher traffic loading. As an example, adding the 30% FEC overhead to a video frame means that at most 70% of IP packets are needed to decode the frame. The FEC overhead can be optimized to maximize the system capacity.

IV. Potential 5G Enhancements to Improve XR Performance

A. SPS/CG Enhancements

In order to ensure more resources are available for XR transmissions, the 5G NR Semi Persistent Scheduling (SPS) and configured grant (CG) features can be leveraged since these features configure periodic DL and UL resources, respectively, for a given user without the control overhead. These features are well suited for XR applications because of their high bit rate requirement (especially on the DL) and the periodic nature of XR traffic. In addition, the SPS and CG features can be optimized for XR performance improvement. Some these optimizations are outlined in:

Name	*Description*	*Benefits for XR*
SPS/CG Occasion Optimization	Dynamically activate SPS/CG occasion(s) that is(are) to be used by the UE using Downlink Control Indicator (DCI).	• Reduce unnecessary SPS decoding and NACK messages • Reduce wasted resources for unused CGs
UE-Assisted CG parameter Modification	Enable UE-based semi-static and dynamic mechanisms for adapting CG resources to UL XR traffic	Make more resources available for multiplexing more XR UEs on the UL.

B. Traffic Awareness in the Radio Access Network (RAN)

1) Beam Management and Measurement Configuration

To improve the performance of XR traffic over the 5G networks, especially for FR2 operation, RAN awareness of XR traffic characteristics can be used to trigger beam management and measurement configuration updates. Application information such as XR viewport or pose information can facilitate the UE/gNB prediction of positioning, channel and beam changes so that necessary preparation can be made ahead of the time. This could lead to XR performance and mobility improvement and reduction in power consumption.

2) Application Data Unit

The latency and reliability QoS parameters in 5G are at the IP packet level, e.g., PDU on the N6 interface towards UPF. XR clients, however, need a minimum granularity of information (referred to as an *Application Data Unit*) to conduct data processing at a higher level. As an example, ADU can be a video frame partitioned into many IP packets. New QoS parameters at the ADU level are needed for the following reasons. First, packet error rates (PER) can be drastically different from ADU error rates. For an ADU that is partitioned into 1000 packets and needs all packets for decoding, PER of 1e-3 results in one packet loss but 100% ADU error rate. On the other hand, forward error correction can tolerate a high packet error rate to decode an ADU. Second, ADU delay budget is different from packet delay budget (PDB), e.g., when encoding delay spreads out the packets of a video frame over time, resulting in a large span of PDBs to meet the deadline of the video frame. A 5G system with ADU-level QoS awareness and content policies is better suited to meet the XR performance requirements.

3) Benefits

a) Delay-aware scheduling

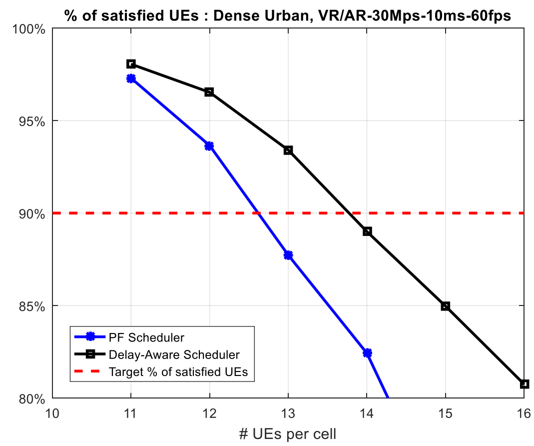

Fig. 6: Impact of delay-aware scheduling

If the scheduler at a gNB is aware of packet deadlines, it can prioritize users that are approaching the deadline instead of using a proportional-fair metric. In simulation results [6], we see increase in XR performance with such scheduler changes.

b) User traffic staggering

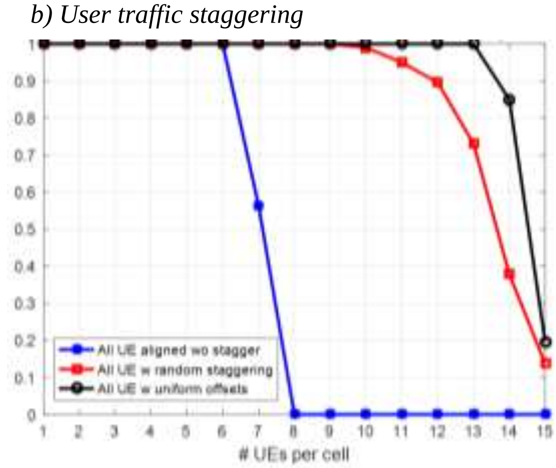

Fig. 7: Effect of staggered arrival across users

Since multiple users in a cell compete for resources, it would be beneficial if the frame times of two different users are offset relative to each other as shown in Fig. 9. In comparison, synchronized arrivals may increase the burden on a cell to deliver more bytes within the same delay budget. Fig. 7 shows the proportion of satisfied users for different schemes. There is a clear benefit of uniformly spacing out the frame times of different users. Realizing such benefits would require a mechanism for the RAN to interface with the application server generating the frames.

C. Interference Coordination

Massive MIMO allows base stations to get beamforming gain by enabling more focused beam transmission. However, the interference from neighbor cells will also be more focused (Fig. 8), resulting in large fluctuations in SINR depending on the neighbor cell traffic patterns. In such conditions, reactive approaches based on channel state feedback may be insufficient given the tight latency requirements.

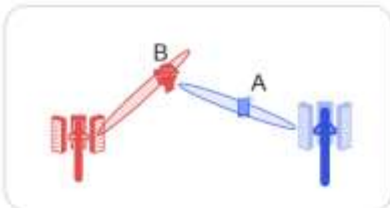

Fig. 9: Inter-cell interference can significantly impact XR performance

Coordination across gNBs to reduce inter-cell interference at XR UEs could prove crucial in improving XR performance. As an example, if two UEs are associated to different gNBs and a transmission beamformed to the first UE jams the second UE, then such UEs could be scheduled on different resources. In simulation results submitted to 3GPP [6], we observed the percentage of satisfied UEs (i.e., UEs with > 99% frames delivered within the delay budget) in a 3 UE/cell dense urban layout improved from **88.9%** to **93.6%** due to such interference coordination.

D. Network Coding

Application of Network Coding [7], [8] in RAN could be used to improve XR capacity. End-to-end enhanced solution by considering application layer traffic characteristics and requirements and utilization of the RAN protocol stack adaptations offer potential for improved capacity.

XR traffic characteristics include relatively high data rate, stringent latency bound and reliability requirements. Given these requirements, we investigate if addition of Network Coding (NC) in the RAN protocol stack provides performance benefits over other existing NR schemes, such as baseline HARQ and PDCP duplication. Redundancy added upfront in case of NC could help XR traffic to fulfil latency and reliability requirements without having to resort to HARQ/RLC retransmissions that would increase the delay of packet reception, especially in cases of blocking. Compared to the PDCP duplication, NC can offer adaptive redundancy, which allows for more efficient operation by adapting to the current traffic load and reliability/latency requirements. Constant redundancy of PDCP duplication may result in excessive system load, stalling the traffic and reducing capacity.

The considered design is based on introducing the NC sublayer below PDCP. PDCP packets are segmented into a

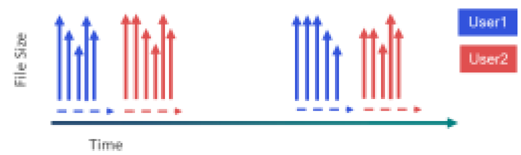

Fig. 8: RAN-aware traffic generation

suitable number of sub-packets, network encoded with desirable redundancy, and handed to RLC, MAC, and PHY layer for OTA transmission. The placement for NC sublayer as a part of the RLC layer was motivated by the existing RLC segmentation functionality, flexibility to perform NC on specific Radio Bearers, and possibility for dynamic adaptation of NC parameters based on channel conditions.

1) Simulation Assumptions

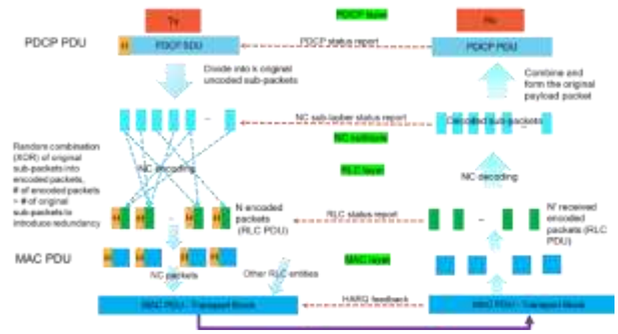

Fig. 10: Protocol Stack and Lifecycle of NC Packets

The performance analysis is based on system simulations with 3GPP Urban Micro (UMi) model with 100m inter-cell distance. Carrier aggregation (CA) is considered as an inter-band two Component Carriers (CCs) CA on 28GHz and 39GHz, and three CCs CA on 28GHZ, 28.7GHz, and 39GHz carrier frequencies. The simulated bandwidth is 200MHz per carrier with 95% bandwidth efficiency. There are 19 sites with 57 gNBs in total. 3GPP downlink XR traffic model with 100Mbps and 60fps is considered.

Capacity of three schemes, baseline, PDCP duplication, and NC (as described in Fig. 10), are compared.

Baseline scheme assumes packet split into sub-packets that are routed evenly on available CCs, without adding any redundancy (error recovery is achieved through HARQ).

The PDCP duplication scheme transmits a copy of a packet on each available CC. Receiver successfully receives the packet when at least one copy is received correctly.

The NC scheme assumes Raptor code [8]. As shown in Fig. 10, a packet is first divided into k sub-packets and encoded into n sub-packets. The n sub-packets are evenly routed for transmission over the available CCs. Receiver can recover the original packet with probability p if it receives any m out of n encoded sub-packets. We consider that an original packet is successfully received when any $m=k+1$ sub-packets are correctly received.

The delay deadline of the XR traffic is 10ms. The capacity is defined as the percentage of UEs with 99% of their packets successfully delivered by the delay deadline.

2) Simulation Results

Fig. 11 presents the system capacity for 2 CC CA. We assume periodic blocking (4 ms for every 10 ms) on 28GHz CC and no blocking on 39GHz CC. In the baseline(2cc), traffic is transmitted over both CCs, irrespective of the blocking condition. In the baseline(1cc), all traffic is transmitted over

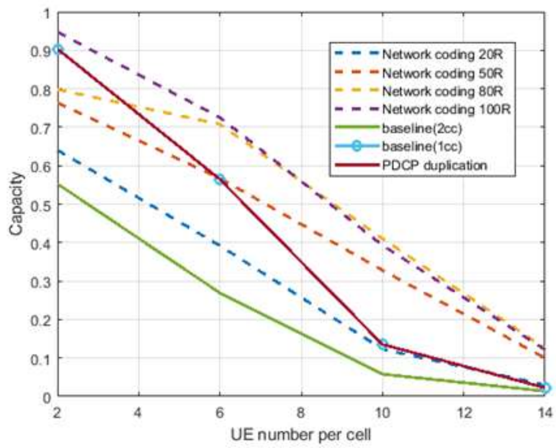

Fig. 11: System Capacity for 2 CC CA (28 & 39GHz)

the non-blocked CC. The NC scheme is analyzed for 20%, 50%, 80%, and 100% redundancy. NC with 100% redundancy achieves the best performance, especially for larger number of UEs, due to the diversity gain introduced by the redundant packets. The baseline(1cc) achieves similar performance as PDCP duplication, suggesting that if blocking can be detected, the entire traffic should be directed off the blocked CC. This, however, may not always be timely achieved, and in those cases the diversity schemes can provide benefits.

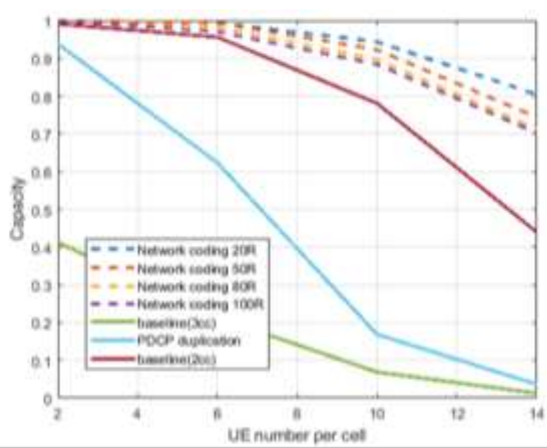

Fig. 12: System Capacity for 3 CC CA (28, 28.7, 39GHz)

Fig. 12 presents the system capacity for 3 CC CA with periodic blocking only on 39GHz CC. In the baseline(3cc), the traffic is transmitted over all 3 CCs (irrespective of the blocking condition), while in the baseline(2cc) all traffic is transmitted over the non-blocked CCs. The NC with 20% redundancy achieves the best performance due to the diversity gain and robustness introduced by the redundant packets. Note that the needed NC redundancy for 3CC is smaller than for 2 CC (20% vs 100%), which is expected due to the increased diversity order. The flexible and adjustable redundancy of NC overperforms the PDCP duplication, as the latter suffers due to the increased loading caused by unnecessarily high redundancy. The baseline(2cc) outperforms the baseline(3cc) (which lacks redundancy to compensate for data loss during blocking) and PDCP duplication but assumes genie-aided avoidance of blocking.

E. *Mobility*

The 3GPP Release-16 5G NR Dual Access Protocol Stack (DAPS) handover (HO) feature which facilitates zero ms interruption during HO can be leveraged for XR mobility support. The feature was mostly developed for FR1 non-Carrier Aggregation (i.e. non-CA) scenarios, therefore, FR1 extensions to CA scenarios and support for FR2 would be required. For example:

- Support for beam management and spatial division multiplexing during HO and beam prioritization during collision between source and target cell communication.
- Support for Carrier Aggregation or multi-TRP features at HO without explicit carrier activation/deactivation.

V. CONCLUSIONS

In this paper, we presented system-level evaluation results for the performance of XR applications over a 5G NR system for sub-6 GHz (FR1) and millimeter wave (FR2) bands. Both uplink and downlink traffic of a split-rendering system have been studied. FR1 results for the dense urban scenario show that 5G offers good performance for XR applications. FR2 results for the indoor hotspot scenario also show good XR performance, leveraging the large bandwidth offered by FR2. The UL VR capacity of FR2 can be significantly improved by leveraging schemes that enable user multiplexing in the time, frequency, and spatial domains. We also discussed many techniques to further improve XR performance. Enhancements related to traffic-awareness in the RAN, interference coordination, network coding, semi-persistent scheduling and mobility are expected to further enable 5G systems to support emerging applications like XR.

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