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# Enabling Efficient Point-to-Multipoint Transmissions in 5G RAN

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*The first release of 5th Generation (5G) technology from 3<sup>rd</sup> Generation Project Partnership (3GPP) Rel'15 has been completed in December 2018. An open issue with this release of standards is that it only supports unicast communications in the core network and Point-To-Point (PTP) transmissions in the Radio Access Network (RAN), and does not support multicast/broadcast communications and Point-To-Multipoint (PTM) transmissions, which are 3GPP system requirements for 5G applications in a number of vertical sectors, such as Automotive, Airborne Communications, Internet-of-Things, Media & Entertainment, and Public Warning & Safety systems. In this article, we present novel mechanisms for enhancing the 5G unicast architecture with minimal footprint, to enable efficient PTM transmissions in the RAN, and to support multicast communications in the Rel'15 core as an in-built delivery optimization feature of the system. This approach will enable completely new levels of network management and delivery cost-efficiency*

## Introduction

5G technology (3GPP Rel'15), composed of New Radio (NR), Next Generation Radio Access Network (NG-RAN), and 5G Core (5GC), has been completed in 2018. Rel'15 has been structured in three phases: First, a non-standalone (NSA) version that requires Long Term Evolution (LTE) for the control plane has been specified at the beginning of 2018. The 5G NR NSA leverages not only the LTE's evolved Packet Core (ePC), but also the LTE's Radio Access Network (RAN) for wide coverage and mobility. It introduced 5G NR to enhance the user plane performance and efficiency using dual connectivity across the LTE and NR bands. The second phase of Rel'15, covers the stand-alone version of 5G, enabling deployments without any LTE infrastructure. In the last stage of Rel'15 specification further habilitates more architecture options for hybrid LTE and

5G NR deployments using the 5GC network. It basically allows using the 5GC to inter-work with both E-UTRAN and NG-RAN.

Driven by the challenging requirements for enhanced Mobile BroadBand (eMBB) and Ultra-Reliable Low-Latency Communication (URLLC) of the International Mobile Telecommunications for 2020 and beyond (IMT2020)<sup>1</sup>, and the ambition to cover use cases for the digitalization of new industries (also known as verticals), 5G NR brings a large number of new options compared to LTE, such as new Forward Error Correction (FEC) codes, Orthogonal Frequency Division Multiplexing (OFDM) waveform numerologies, dynamic frame structures, massive Multiple-Input Multiple-Output (MIMO) schemes, Quality-of-Service (QoS) architecture, support for various distributed and centralized NG-RAN infrastructure implementations, etc [1].

An impending problem of the first release of 5G is that it only supports unicast communications in the core network and point-to-point (PTP) transmissions in the RAN. This limitation may imply an inefficient service provisioning, and utilization of the network and spectrum resources when distributing the same data to multiple users and devices. One of the 3GPP system requirements for the 5G system is to provide flexible multicast/broadcast services [2], since it is considered as an essential feature for 5G applications in a number of vertical sectors, such as Automotive (V2X), Airborne Communications, Internet-of-Things (IoT), Media & Entertainment (M&E) and Public Warning (PW) [3]. Future wireless networks would require flexible and dynamic allocation of radio resources between unicast and multicast/broadcast transmissions within the network. For example, to dynamically offload mass-media traffic in high-density deployments, to enable efficient software and firmware upgrade of IoT devices, or group messaging.

Regarding the 5G multicast architecture, the current state-of-the-art, as well as future trends in technology and service design should be considered in the design process. Services are nowadays being designed through customized means, utilizing

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<sup>1</sup> IMT2020 requirements for massive Machine-Type Communications (mMTC) will be addressed with LTE Internet-of-Things (IoT) solutions LTE for Machines (LTE-M) and NarrowBand IoT (NB-IoT).

information gathered not only from users but also other components of system such as a user device, communication network, data consumption patterns, etc. Such service architectures target high quality of user experience and rely on a unicast link between the user application and the application backend, to deliver customized user content and to monitor connection quality, user engagement, etc. This is often performed in real-time. Moreover, multicast over public networks is not possible, hence over-the-top services will use unicast connectivity by default. Another emerging trend is edge computing, which pushes store and compute resources to Communication Service Provider (CSP) network (e.g. see ETSI's multi-access edge computing [4]). The store and compute resources can be utilized in new caching and content delivery architectures, which can also benefit from multicast transport because the content is in CSP networks.

Currently, 3GPP has added PTM communication capabilities for 4G LTE-Advanced Pro (Rel'13 and Rel'14) for digital television services, machine-type, mission critical and vehicular communications. Two clear trends can be identified: (i) stand-alone deployment of dedicated broadcast networks for digital TV services, and (ii) PTM as RAN delivery optimization feature. 5G Multicast/Broadcast is one of the topics that is being considered for Rel'17, in particular, mixed unicast/multicast mode, to dynamically switch between PTP and PTM transmissions in order to efficiently deliver identical content over the RAN. This has significant potential to leverage downlink and/or uplink unicast, with configurable/dynamic coverage ranging from a single cell to a large area, and multiplexed and possibly seamlessly switched with unicast traffic.

This paper describes a way to enhance the 5G Rel'15 architecture to enable efficient PTM transmissions in the 5G RAN and support multicast communications in the 5GC as built-in delivery optimization features of the 5G mobile system. This approach will open a door to completely new levels of network management and delivery cost-efficiency [5].

## Background

### Multicast/Broadcast in LTE

Enhanced Multimedia Broadcast Multicast Services (eMBMS) was introduced in LTE Release 9, to provide broadcast capabilities to LTE networks. It was an evolution of 3G Multimedia Broadcast Multicast Services (MBMS) developed in Release 6, carrying over the legacy architecture at core level. From the very beginning, eMBMS natively supported Single Frequency Network (SFN) operation, in a delivery mode called MBMS over Single Frequency Networks (MBSFN) [6]. This mode requires to reserve subframes with different

numerologies compared to PTP. The main drawback of this approach is the static setup of SFN areas, unable to adapt to user demand [7]. Later enhancements of eMBMS address this problem by adding to RAN User Equipment (UE) counting (Rel-10) and MBMS operation on Demand or MooD (Rel-12). However, this effort was insufficient for other verticals that can benefit from PTM transmissions, such as vehicular and mission critical communications. Both verticals will modify the existing eMBMS solution to fulfil their specific requirements.

Single Cell Point-to-Multipoint (SC-PTM) was introduced in Rel-13 as an alternative delivery. SC-PTM reuses the PTP physical channels, improving the flexibility by multiplexing together both PTP and PTM, but loses the capability to broadcast in SFN mode.

Rel-14 introduced significant enhancements to eMBMS, both in RAN and core which is referred to as Enhancement for Television (EnTV) services. The main RAN contributions were the capability of having unregistered (Receive-Only-Mode) UEs receive the eMBMS transmissions and improvements in the MBSFN physical layer which is also called further enhanced MBMS (feMBMS) [7]. SC-PTM was enhanced to support vehicular, Narrow Band-Internet of Things (NB-IoT) and enhanced Machine-Type Communications (eMTC) verticals. Rel-16 EnTV is improving the radio performance of the Cell Acquisition Subframe (CAS).

| RELEASE | FEATURES AND IMPROVEMENTS   |
|---------|---|
| 9       | LTE Broadcast is introduced (eMBMS MBSFN)                         |
| 10      | Allocation and Retention Priority for MRB, RAN Counting           |
| 11      | Multi-frequency Deployments                                       |
| 12      | MBMS operation on Demand (MooD)                                   |
| 13      | Single-Cell Point-to-Multipoint (SC-PTM)                          |
| 14      | EnTV: Receive-only-Mode (ROM), feMBMS SC-PTM for V2X, NB-IOT, eMC |
| 16      | 5G EnTV: Enhancements to Cell Acquisition Subframe (CAS)          |

**Table 1:** PTM evolution in LTE

### 5G Release 15-16

5G Rel-15 specifications mainly focus on the design principles of forward compatibility, control-user plane separation, lean and cloud-native system design. Rel-16 studies relate to a multitude of topics including - enhancements for vehicle-to-everything communications, satellite access, wired/wireline convergence, positioning, network slicing and automation for further support of new verticals. One of the key elements of 5G RAN design is to extend the fully distributed

base station architecture to support flexible protocol functionality split between Central Units (CUs) and Distributed Units (DUs), which are interconnected using the F1 interface with control (F1-C) and user (F1-U) plane connectivity between the CU and DU. An overview of the 5G/NR RAN architecture is shown in Figure 1, with the CU including the non-time-critical functionalities (which could be hosted on the cloud), while the DUs would be including real-time functionalities. Such novel architecture enhancements provide a significant opportunity to design an innovative RAN architecture for multicast content in 5G, with minimal enhancements to the unicast functions.

### 5G Multicast/Broadcast Requirements

One of the 3GPP system requirements for 5G is a flexible broadcast/multicast service for three types of devices (eMBB, URLLC and mMTC) [2]. The need of multicast/broadcast and PTM transmissions is also evident in the general system requirements, such as those for efficient content delivery and resource efficiency.

In general, the requirements for 5G multicast/broadcast can be classified into two different operation modes: stand-alone deployment of dedicated broadcast networks which is out of the scope of this work, and the mixed unicast / multicast mode which is our key focus area. Requirements for mixed-mode multicast aims to incorporate PTM transmissions in the RAN as an in-built delivery optimization feature of the network. This requires for e.g., seamless switching between PTP and PTM transmissions, dynamic adjustment of the RAN multicast area based on user distribution (from one cell to several synchronized cells), and efficient multiplexing with PTP transmissions in frequency and time domain. Overall the mixed unicast / multicast mode should have high commonality with unicast, minimizing the additional footprint.

### 5G Multicast Extension, Design Principles and Challenges

As previously mentioned, the 5G multicast extension should support several transmission modes within the same framework: PTP, SC-PTM, and SFN operation mode. Each of these modes are optimal for a variable number of users demanding common content, while taking into account their geographical distribution. In this article, two new logical multicast functions are proposed: gNB-CU-MC and DU-MCF. Together, they enable the delivery of PTM content reusing 5G NR, based on the enhancements presented in [8]. The gNB-CU-MC function enables the dynamic user plane switching between unicast and multicast radio bearers by interworking with the DU-MCF over a new interface: F1-M. The highlighted blocks in Figure 1 describe the overall multicast architecture.

In all transmission modes, the associated logical channels are transmitted on the DownLink Shared CHannel (DL-SCH).

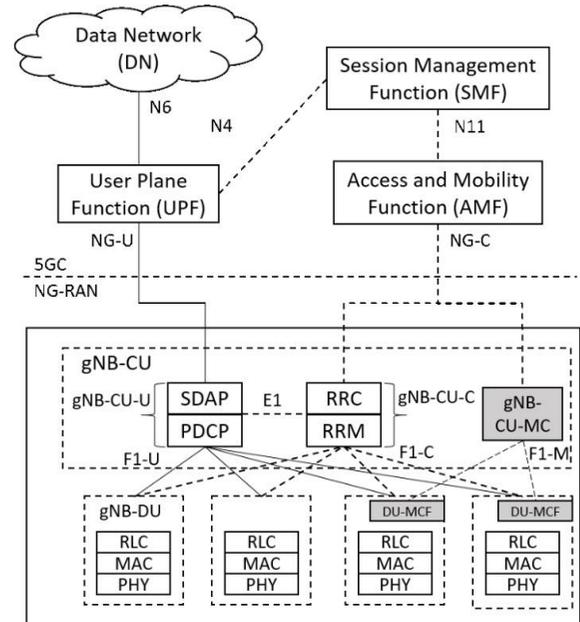


Figure 1: RAN architecture with multicast functionality.

Since PTP is already covered by Release 15, only the new modes which are related to PTM enhancements will be detailed:

SC-PTM reuses most of the PTP physical layer, but with limited link adaptation. By providing a common radio identifier, several users can access the same data. The other mode is SFN transmission. SFN is advantageous for cell edge users since the interference turns into constructive signal. Fulfilling the SFN requirements is not trivial and requires changes to several NG-RAN interfaces.

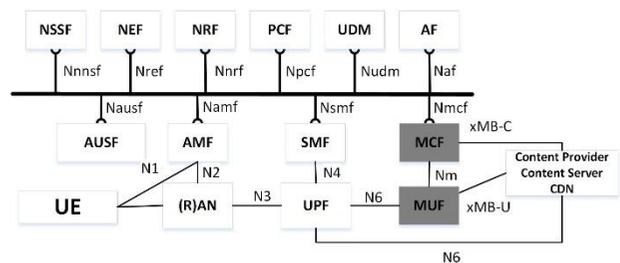
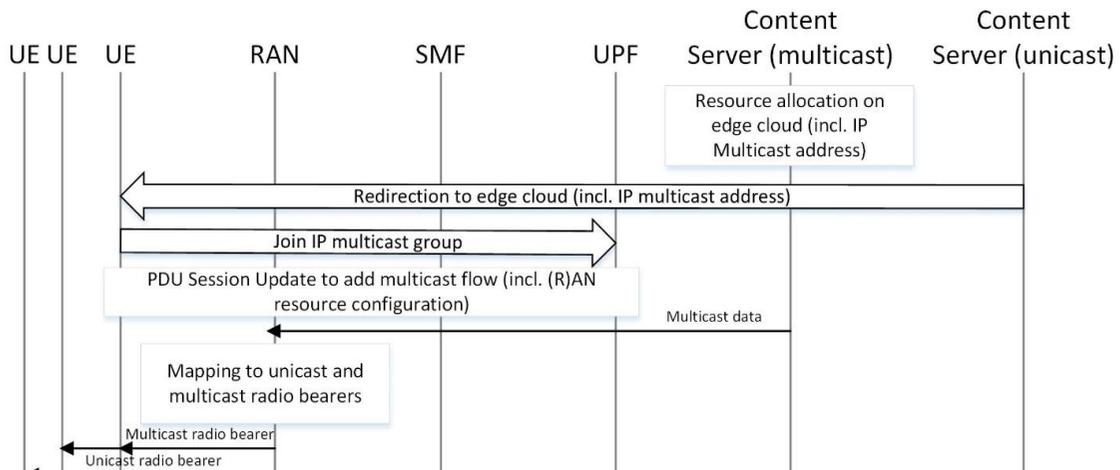


Figure 2: Overall multicast architecture with the added MCF and MUF entities.

As mentioned earlier, every transmission mode is optimal in certain scenarios. Results in literature [9] show different user thresholds when SC-PTM overtakes PTP in terms of spectral efficiency. SFN transmission, on the other hand, homogenizes the quality across cell coverage.

In a multicast capable 5G system, UEs will be configured with Data Radio Bearers (DRBs) for unicast and multicast. This allows seamless adaptation between the PTP and SC-PTM transmission, for example. If the UE is already receiving the



**Figure 3:** Redirection of UEs from Unicast consumption to Multicast.

multicast eligible traffic (i.e., not encrypted) over unicast DRB and there will be an increasing number of UEs interested in the same content, then the network will indicate to unicast UEs to synchronously switch over to multicast DRB to receive the same content, thus improving radio resource usage.

## 5G Multicast Architecture

### 5G Core

Given the current state of technology and future trends with unicast connectivity being the default transport, the 5G multicast architecture through efficient extensions, should benefit from the unicast architecture as much as possible. Either if the multicast content is located in CSP network or not, the 5G multicast architecture can be realized by enhancing the User Plane Function (UPF), and new Network Functions (NFs) such as the multicast control function (MCF) in the control plane, and multicast user function (MUF) in the user plane. It is possible to offer multicast-as-a-service through a service interface similar to the xMB [10] interface. Figure 2 describes the overall architecture.

When a content server receives decision to enable multicast delivery (from RAN), for example, based on the number of requests received from UEs which IP addresses are within a range, then the content server sends a redirection to a multicast source such as a multicast server as shown in Figure 3. Therefore, the multicast server is expected to be reachable via managed network, e.g. located at edge cloud. For security reasons the redirection and session information may be sent via an encrypted transport layer.

### RAN Architecture

5G multicast services are required to cover a multitude of possible deployments with increased flexibility over existing multicast services. While the proposed 5G multicast solution should be capable of enabling existing multicast/broadcast

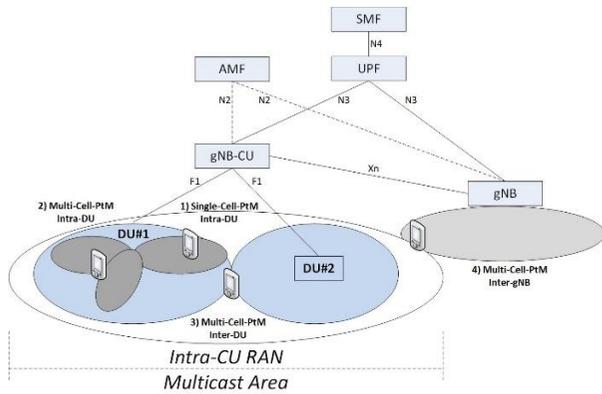
services (e.g. download, streaming, group communication, TV, etc.), the inclusion of new vertical applications are also needed, such as V2X, interactive media and entertainment with personalized content. These services are made available in areas where the number of users during popular events (for e.g., in stadiums) can be high and the user distribution within the multicast area will change over the time.

In the context of multicast, the RAN is aware of UE's interest to receive data from IP multicast group, as well as the radio channel conditions of the interested UEs. Thereafter and if the number of UEs is small, RAN uses link adaptation, beam forming and other techniques to improve the signal quality, throughput and the overall spectral efficiency. As the number of UEs grow, the link adaptation and other techniques become less effective [9].

Even if the unicast data activity can fluctuate significantly or there is no active unicast data transmission or reception, the multicast data must be received continuously without interruption. A new Radio Resource Control (RRC) state, named RRC\_INACTIVE, provides power saving and does not consume radio resources during low-activity unicast periods. Furthermore, from connection management perspective, the UE remains in connected state to the 5GC.

User unicast activity, number of users and their location can bring to network multiple choices on how to best deliver the multicast traffic. In case a sufficiently low number of sparsely located UEs are having high unicast activity, it may be best for the RAN to deliver the multicast traffic using a mapping procedure to unicast DRB with link adaptation. When the number of UEs receiving multicast traffic increases, the system capacity gets lower compared to the same multicast traffic being transmitted using multicast DRB. In this case, the UEs are configured with both unicast DRB and multicast DRB. In scenarios such as stadium events, the number of multicast users

are typically so high that the UEs interested in offered multicast content can be always configured using the multicast DRB.



**Figure 4:** Deployments of the RMA, in function of the transmitters involved in the synchronization.

To solve the aforementioned challenges and new requirements, we propose the RAN Multicast Area (RMA) mechanism, which takes into account the UE activity, number of devices and their geographical distribution. RMA is defined as the multicast area consisting of a cell or a list of cells which identifier is broadcasted as part of the System Information, representing the geographical area where the requested multicast service is available. The RMA is deployed and controlled by RAN, and the anchor gNB terminating the IP multicast defines the RMA configuration and distributes the data over Xn interface to all the gNBs which belong to the RMA. The RMA area could also be dynamically managed over Xn interface.

Inside the RMA, the UEs are required to be initially in RRC\_CONNECTED state, that means, the 5G Core has context information of all the UEs receiving a multicast transmission. This approach allows the system to reuse all the security procedures already existing in Rel'15 to avoid unwanted users to eavesdrop multicast transmissions.

UE can perform serving cell reselection when in RRC\_INACTIVE state and the multicast DRB reception is provided for the whole RMA. To ensure service continuity inside a RMA, UE is expected to notify the network only if the serving cell coverage or quality becomes lower than the neighbouring cell outside the current RMA. If UE receiving multicast in RMA transitions to RRC\_IDLE state, UE will not notify the network and service continuity for multicast cannot be provided.

By employing the RMA concept, the RAN has the knowledge of exact resource utilization, number of UEs in certain radio conditions and UE measurement information, thus the best understanding when to switch from unicast to multicast transmission. In practise this means switching between unicast

DRB and multicast DRB. Compared to legacy multicast solution, the decision to deliver the multicast data is moved from fixed core network deployment to RAN with flexible multiplexing capability.

### Synchronization Options

As previously mentioned, user activity, their number and their geographical location are the main parameters that will define the RMA. To ensure synchronous transmissions, the same Modulation and Coding Scheme (MCS) and the same assignation to physical RBs (PRBs) must be followed by every transmitter forming the RMA. Another challenge to overcome is when the transmitters on a network experience diverse network delays. If the different delays experienced are high enough, SFN operation is not possible without additional help of a protocol that compensates these delays. In the case of MBMS, this protocol is called SYNC.

Depending on which cells are included in the RMA, three different synchronization scenarios will occur as shown in Figure 4. In order to perform an analysis of the synchronization options, an assumption is made, that cells served by a DU-MCF are geographically close so they do not experience noticeable network delays between them.

The first synchronization scenario occurs when every cell involved in the multicast transmission is within the same gNB-DU. The second SFN synchronization scenario considers cells belonging to two or several gNB-DUs governed by the same gNB-CU to form the RMA. Lastly, for the third SFN synchronization scenario, the relevant RMA is formed by cells belonging to two or more gNB-CUs.

Common radio parameters, common scheduling of multicast data and delay compensation are the main requirements imposed by SFN operation. In Release 15, not all parameters can be enforced across different cells. While scrambling, numerology and Demodulation Reference Signal (DMRS) can share the configuration between the transmitters, there are no standardized means to enforce common scheduling and MCS. Interfaces inside the gNodeB and RAN should be accommodated to support the required functionality. For the delay compensation, a protocol like SYNC is necessary to ensure that every transmitter is radiating the same payload.

### 5G PTM performance evaluation

This section presents performance evaluation of 5G PTM which is designed by embedding PTM enhancements on top of 5G NR and architecture. The system-level simulator used in this document is being used to perform IMT-2020 evaluations based on the guidelines in [12]. It has been calibrated, as shown in [13], against 3GPP's system level simulators. Accurate spatial channel models are used based on 3GPP TR 38.901 [17]. An emulation of a communication network consisting of multiple

base stations and numerous UEs, gateways, application servers etc., i.e., including layer-2/3 and higher layer protocol functionalities.

The considered scenarios, for 5G PTM performance evaluation, are taken from ITU-R test environments [14] in coordination with the work in [7][15] which has performed benchmarking evaluation of LTE-A PTM by using ITU-R based environments. The scenarios include:

- Urban 100% indoor: urban eMBB with 100% penetration of indoor UEs,
- Urban 100% outdoor: urban eMBB with 100% penetration of outdoor UEs,
- Rural 100% indoor: rural eMBB with 100% penetration of indoor UEs,
- Rural 100% outdoor: rural eMBB with 100% penetration of outdoor UEs, and
- Indoor office hotspot scenarios for eMBB use case.

The spectral efficiencies that 5G PTM provide, via SC-PTM adquisition, are compared with that of 5G unicast (average and 5-%ile user spectral efficiencies) in Figure 5, Figure 6, Figure 7, Figure 8, Figure 9 for urban 100% indoor, urban 100% outdoor, rural 100% indoor, rural 100% outdoor and indoor office hotspot scenario, respectively for various number of UEs. Herein, the major observations are:

- 5G unicast fully outperforms 5G PTM in case of lower number of UEs. Examples are urban 100% indoor for 10 – 15 UEs per cell; urban 100% outdoor for 10 -17 UEs per cell; and indoor office hotspot for 50 - 100 UEs in office.
- In some cases, the 5G unicast provide better average spectral efficiency than 5G PTM while the cell-edge performance (5-%ile user spectral efficiency) is lower for unicast than PTM. Examples are urban 100% indoor for ~15 – 30 UEs per cell; urban 100% outdoor for ~17 - 30 UEs per cell; rural 100% indoor for 10 – 37 UEs per cell; rural 100% outdoor for 10 - 34 UEs per cell; and indoor office hotspot for 100 - 230 UEs in office.
- For very high penetration of UEs, the 5G PTM fully outperforms 5G unicast. Examples are urban 100% indoor and urban 100% outdoor for >~30 UEs per cell; rural 100% indoor > ~38 UEs per cell; rural 100% outdoor for > ~35 UEs per cell; indoor office hotspot scenario for > ~230 UEs in office.

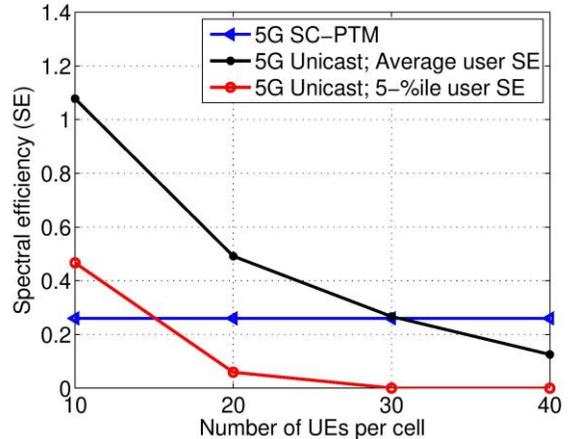


Figure 5: Urban 100% indoor scenario

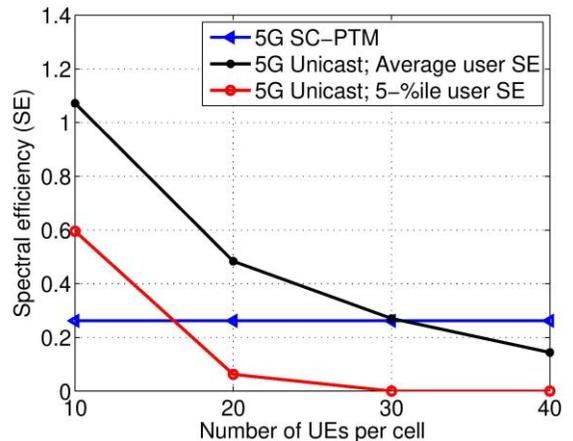


Figure 6: Urban 100% outdoor scenario

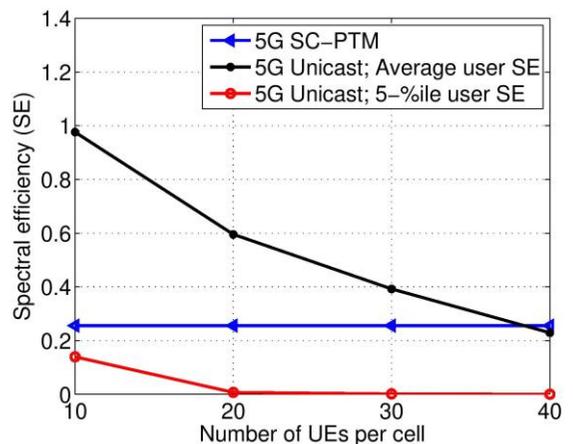


Figure 7: Rural 100% indoor scenario

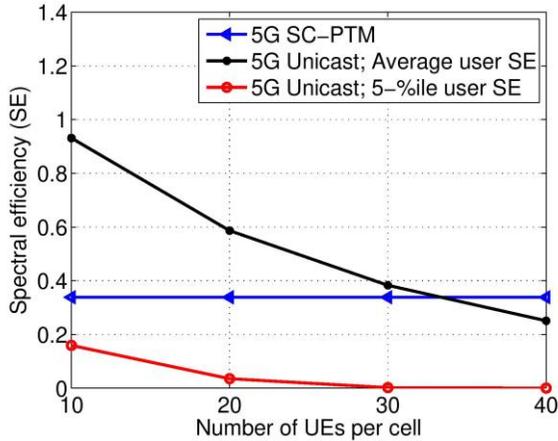


Figure 8: Rural 100% outdoor scenario

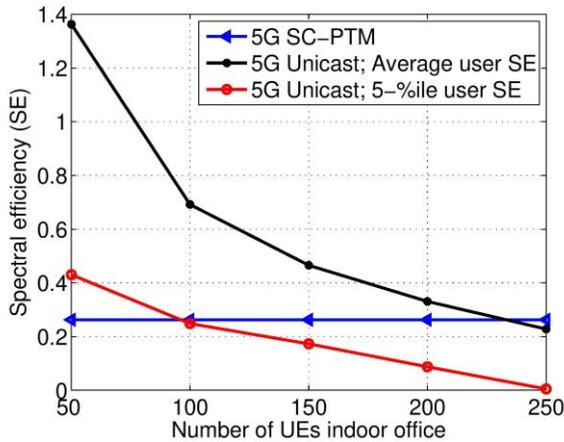


Figure 9: Indoor office hotspot scenario

## Summary and conclusion

The introduction of PTM transmissions in the 5G RAN and multicast support in the core network will increase the efficiency of common content delivery to multiple users or devices. In this work, we propose an end-to-end architecture for 5G multicast which goes beyond the current considerations for LTE Broadcast which solely exists as an isolated service. PTM transmissions could then be implemented in a flexible and dynamic manner, as an essential RAN delivery tool, such that PTM transmissions become an in-built RAN functionality without any special considerations in the core network, being possible to dynamically and seamlessly switch between PTP and PTM transmissions over the dynamically configurable RAN multicast area. Through such enhancements, 5G could provide a unified framework for PTM and multicast content delivery for relevant verticals and applications, including automotive, airborne, IoT, media and entertainment, and public warning and safety. Moreover, this work has shown performance comparison

of 5G PTM and 5G unicast which is baseline for PTM enhancements. The key observations include 5G unicast fully outperforms 5G PTM in case of lower number of UEs. In some cases, the 5G unicast provide better average spectral efficiency than 5G PTM while the cell-edge performance (5-%ile user spectral efficiency) is lower than that of PTM for medium number of UE. However, for high penetration of UEs, the 5G PTM fully outperforms 5G unicast.

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