DY-RUM: Dynamic Resource Allocation for Converged Unicast and Multicast Transmission in 5G and Beyond

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***Abstract*—With the proliferation of cellular networks, there has been an unprecedented surge in multimedia mobile data traffic. Managing this massive data traffic has become increasingly intricate due to limited resource availability. To address this limitation and for improved resource utilization, one of the existing approaches suggests augmenting the unicast transmission with the multicast transmission. However, as we show in this article, a simple replacement of unicast transmission with multicast transmission may not achieve the most efficient results. In order to achieve a more efficient resource utilization in the network, we propose a DYnamic Resource allocation scheme for converged Unicast and Multicast (DY-RUM) transmissions. The scheme has been proposed in the context of the Fifth Generation (5G) mobile communication system. To implement this scheme, we use the Open Radio Access Network (O-RAN) architecture for the 5G system, which provides a suitable setting for the scheme. We also present simulation results affirming the effectiveness of the proposed scheme in improving resource utilization for converged unicast-multicast transmissions in 5G and beyond.**

***Index Terms*—Dynamic Resource Allocation, multicast transmission, unicast transmission, 5G broadcast, O-RAN.**

I. Introduction

The rapid expansion of the Fifth Generation (5G) mobile communications network is evident, with projections indicating that the total 5G subscriptions are projected to reach 1.6 billion by the end of 2023, marking a staggering growth of 500 million subscriptions within just one year [1]. Mobile data consumption per smartphone is also anticipated to reach 56 GB per month by 2029 [1]. In this scenario, there is an urgent need to address the challenge of handling exponentially increasing data traffic in cellular networks.

Multicast wireless transmission with its innate capacity to serve a group of users via shared radio resources, may prove useful in this regard. Nevertheless, as will be shown in this article, opting for multicast transmission for all potential users may not be the optimal approach towards utilizing the resource. Instead, a dynamic resource allocation scheme for converged unicast and multicast transmissions may enable more efficient utilization of radio resources in 5G and beyond.

Here, we review the existing literature on the usage of multicast transmissions to improve resource utilization in mobile networks. In [2], the authors emphasize the need for integrating unicast and multicast services within a unified framework in the 5G network, although no specific framework is discussed. In [3], authors investigate the utilization of a hybrid mode that concurrently utilizes multicast, broadcast, and unicast resources over the same physical channel in 5G New Radio (NR), demonstrating superior coverage to cell-edge User Equipment (UE) compared to Evolved Multimedia Broadcast and Multicast Services (eMBMS). [4] makes an endeavour to elucidate the optimal choice for the eMBMS network configuration based on the specific requirements of operators. [5] introduces a multicast resource allocation scheme that limits the transmission rate based on the worst channel condition experienced by the requesting UE. [6] proposes a radio resource management framework to handle unicast and multicast multi-layer video services while [7] proposes an approach considering channel conditions for content delivery, wherein UEs with good channel quality receive content via unicast, and those with poor conditions receive content via multicast. [8] offers a comprehensive survey on multicasting in wireless access networks.

This paper introduces a novel DYnamic Resource Allocation scheme for a converged Unicast and Multicast (DY-RUM) transmission in 5G and beyond. The scheme results in an improved resource utilization when a group (set) of users is accessing the same content, e.g., a news bulletin or a particular sporting event. The scheme includes a dynamic resource allocation algorithm along with a mechanism to use the algorithm in an Open Radio Access Network (O-RAN)-based framework for 5G and beyond. The key entity that enables the algorithm in O-RAN is the unified RAN Intelligence Controller (RIC).

The DY-RUM algorithm divides the set of such users into two disjoint subsets, unicast and multicast users. An individual user belonging to the unicast subset receives data through dedicated unicast transmission, while users belonging to the multicast subset receive data through a shared multicast transmission. The scheme assumes separate unicast and multicast transmitters. The distribution of users in two subsets depends on the channel condition experienced by the users under each of these transmitters, which further determines resource allocation across unicast and multicast transmissions. A key innovation behind the proposed algorithm is a dynamic reconfiguration of two subsets due to the run-time arrival of users and on the basis of individual user's radio conditions. The dynamic reconfiguration of sets leads to a change in the allocation of radio resources for converged unicast and multicast transmissions. To the best of our knowledge, no other work proposes dynamic resource allocation for converged unicast-multicast transmissions driven by the dynamic user arrival and on the basis of the radio condition experienced by the users under unicast and multicast transmissions.

O-RAN is a next-generation radio access network architecture transforming RANs towards open, intelligent, virtualized and fully interoperable radio access networks [9]. Following the O-RAN approach, the 5G base station, also known as gNB, is disaggregated into multiple entities with open interfaces between them: a Centralized Unit (O-CU), a Distributed Unit (O-DU), and a Radio Unit (O-RU). The CU is further split into two logical components: the Control Plane (O-CU-CP) and the User Plane (O-CU-UP). RIC is a key software-defined element within the O-RAN architecture that controls all RAN functions, such as O-CU and O-DUs. RIC enhances radio access networks by introducing agility and programmability to it [9]. This capability is also demonstrated in this article, as mentioned below. In the context of the proposed algorithm, the role of RIC is most important as it dynamically determines the appropriate data transmission mode, unicast or multicast, for each user (UE), leveraging the channel state information provided by the UEs and also allocates radio resources accordingly. We consider Third Generation Partnership Project (3GPP) 5G New Radio (5G-NR) technology for both unicast and multicast-broadcast transmission. As mentioned earlier, we consider separate transmitters for unicast and multicast; these are instantiated as separate (O-DU+O-RU)s [9]. They work under the control of a RIC and an O-CU-CP. The usage of RIC and the O-RAN framework to control resource allocation in a converged unicast-multicast setting is a unique feature of our paper.

The rest of the paper is organised as follows: Section II provides a discussion on the system model. Section III contains the proposed DY-RUM algorithm and its explanation. A simulation based evaluation of the proposed algorithm is there in section IV. Simulations illustrate DY-RUM's improved performance compared to unicast-only or multicast-only algorithms. Section V provides the conclusion and future work.

II. System Model

The system model comprises a dedicated 5G multicast-broadcast cell delivering multicast-broadcast services to UEs within its coverage area. Besides, we consider multiple 5G unicast cells for unicast transmission, which are uniformly distributed throughout the region, overlapping with the coverage area of one 5G multicast-broadcast cell, as depicted in Figure 1. It is assumed that the 5G multicast-broadcast cell has a larger coverage area than 5G unicast cells, which is in line with the typical deployment scenario. Each cell, be it a unicast cell or a multicast-broadcast cell, is supported by an individual O-DU and O-RU combined entity, shown as O-DU+O-RU in Figure 1. To enhance clarity, the illustration shows a lesser number of 5G unicast cells, but in our simulations, we deploy 5G unicast cells extensively to ensure each user is under the coverage of both multicast (5G multicast-broadcast DU) and unicast (5G unicast DU) transmission, leaving no user unserved. Please note that the model is generic and can be used with other combinations of multicast-broadcast & unicast transmission technologies, e.g., Advanced Television Systems Committee 3.0 (ATSC 3.0) or Long Term Evolution (LTE) Further evolved MBMS (FeMBMS) for multicast and 5G-NR for unicast transmission. The only assumption is that separate base stations (radio transmitters) are used for multicast and unicast delivery. We think the assumption is reasonable as multicast/broadcast transmission has different characteristics viz-a-viz unicast and is typically optimized differently than unicast transmission.

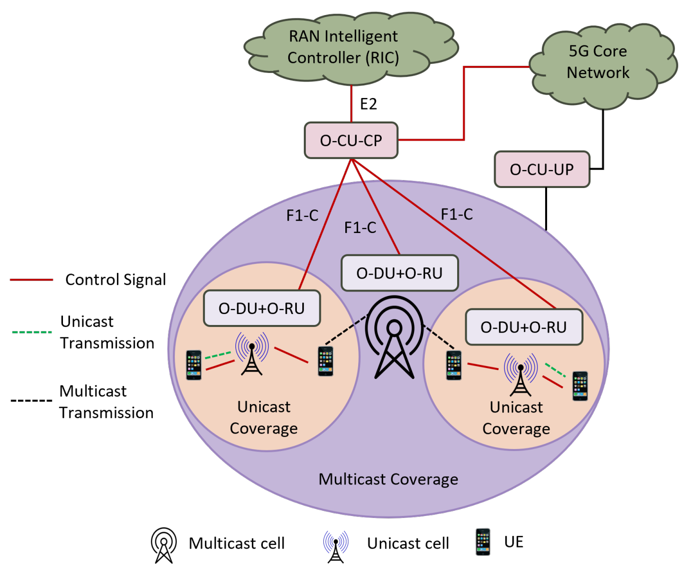

Fig. 1. O-RAN based deployment scenario.

A RIC is employed in the system to oversee and administer both unicast cells (5G unicast O-DUs) and multicast cells (5G multicast-broadcast O-DU), as depicted in Figure 1. The RIC is separated from the O-CU-CP via a standardized interface (E2) whereas the O-CU-CP is interfaced with the O-DU+O-RU via F1-C. The RIC uses the E2 interface to receive the channel state information (Channel Quality Indicator (CQI)) for both the unicast and multicast/broadcast cell via 5G unicast O-DU. An important assumption here is that each UE is capable of dual-connectivity, i.e., a UE is always connected to a unicast O-DU+O-RU to exchange control information (e.g., CQI) through a 5G unicast cell while data can be received via either the 5G unicast cell or 5G multicast-broadcast cell. Utilizing the CQI, the RIC assesses the most efficient approach to serve individual UEs, deciding between the dedicated (unicast) transmission or shared (multicast) transmission and allocates radio resources accordingly. A single data stream flows from the 5G core network to the RAN (O-CU), which O-CU uses, under the control of RIC, to deliver data to UEs either in unicast (Point-to-Point mode by creating a separate copy of data stream for each UE) and/or multicast (Point-to-Multipoint mode, by sending a single data stream) delivery modes. This is also in line with the design of the multicast-broadcast services in 3GPP 5G [10].

The system model considers dynamic UE arrival (i.e., content requests), which follows a Poisson process. We also assume that UEs are mobile, so their channel conditions may vary over time. Although a single dedicated 5G multicast-broadcast cell and multiple 5G unicast cells have been considered in the system model, it can be generalized to include multiple 5G multicast-broadcast cells also. It is assumed that each UE is simultaneously associated with one 5G unicast cell and one 5G multicast-broadcast cell, the ones which provide the best channel quality to the UE.

III. Proposed DY-RUM Algorithm

Table I provides a comprehensive list of notations and their respective descriptions, serving as a reference for terms used consistently throughout the paper. In this section, we initially define the problem. Subsequently, we introduce the proposed DY-RUM algorithm for the problem formulated as $\mathbb{P}$. We consider that each UE q has a minimum rate requirement $\mathcal{D}_q$ to guarantee the required Quality of Service (QoS). For all UEs accessing a specific content, the rate requirement is assumed to be the same irrespective of the mode (unicast/multicast) being used to serve a UE. When a new UE arrives in the system (network), it associates itself with a 5G unicast cell, providing it with the best signal quality and reports the CQI as observed by it, both for the best 5G multicast-broadcast cell and the 5G unicast cell. Based on the collected CQI reports and the required data rate, the number of Resource Blocks (RBs) (R_q^u, R_q^m) are calculated needed to serve the UE via the 5G-NR cell (unicast transmission) and 5G broadcast cell (multicast transmission), respectively as per 3GPP standard [11], [12], [13]. The significance of the CQI reporting for both unicast and the broadcast cell and the consequent R_q^u, R_q^m calculation for each UE is discussed further.

When a new UE enters the system, three attributes are assigned to the UE: a unique UE ID $q \in \mathbb{Z}_+$, R_q^m and R_q^u. As mentioned above, R_q^m and R_q^u are calculated based on the CQI reports collected from the UE. The DY-RUM algorithm assigns the UE either to the set $\mathcal{S}_u$ or the set $\mathcal{S}_m$. If UE $q \in \mathcal{S}_u$, it is served via unicast transmission and a dedicated set of RBs is allocated to the UE. Thus, the total number of RBs required to serve all UEs in set $\mathcal{S}_u$ denoted by R^u is the aggregate sum of the RBs required by each UE in $\mathcal{S}_u$. Formally, R^u can be defined as follows:

TABLE I
Notations and their description

Notations	Description
$\mathcal{S}$	Set of UEs in the system accessing a specific content
$\mathcal{S}_u$	Set of UEs served via unicast transmission
$\mathcal{S}_m$	Set of UEs served via multicast transmission
$\mathcal{R}_q^u$	RBs required to serve UE q via unicast transmission
$\mathcal{R}_q^m$	RBs required to serve UE q via multicast transmission
A	Sorted list of all UEs in set $\mathcal{S}$ in ascending order of $\mathcal{R}_q^m$
$A[\phi']$	UE stored at index ϕ' in list A
$R^u_{A[\phi']}$	RBs required to serve UE at index ϕ' in A via unicast transmission
$R^m_{A[\phi']}$	RBs required to serve UE at index ϕ' in A via multicast transmission
$\mathcal{R}^u$	Number of RBs required to serve all UEs in set $\mathcal{S}_u$
$\mathcal{R}^m$	Number of RBs required to serve all UEs in set $\mathcal{S}_m$
$\mathcal{R}^s$	Total number of RBs required to serve all UEs in set $\mathcal{S}$ i.e., $q \in \mathcal{S}_u \cup \mathcal{S}_m$
$\mathcal{D}_q$	Minimum rate requirement of UE q
$\mathcal{D}_q^u$	Rate UE q receives via unicast transmission
$\mathcal{D}_q^m$	Rate UE q receives via multicast transmission

$$R^u = \sum_{q \in \mathcal{S}_u} R_q^u \tag{1}$$

Let R^m denote the RBs required for multicast transmission in the system. Unlike UEs in unicast transmission, a common set of RBs serves all UEs in $\mathcal{S}_m$ for multicast transmission. Please note that the total number of RBs required for multicast transmission in the system is equal to the maximum of the number of RBs required by each individual UE (R_q^m) in the set $\mathcal{S}_m$. This is so because if the UE experiencing the worst channel condition under the 5G multicast-broadcast cell can be provided the required QoS via a set of RBs (and satisfied through multicast transmission), then all other UEs (with better channel quality in the 5G multicast-broadcast cell) in the set $\mathcal{S}_m$ can also be satisfied via the same set of RBs in multicast mode. In fact, this observation is the key insight behind the proposed algorithm. Thus, R^m is obtained as

$$R^m = \max_{q \in \mathcal{S}_m} R_q^m \tag{2}$$

From Equations (1) and (2), the total number of RBs required in the system R^s to serve all UEs, i.e., $\mathcal{S}_u \cup \mathcal{S}_m$ can be obtained as follows:

$$R^s = R^u + R^m \tag{3}$$

A. Problem Formulation

The system aims to allocate every UE in $\mathcal{S}$ either to multicast ($\mathcal{S}_m$) or to the unicast ($\mathcal{S}_u$) sets so that R^s required to serve UEs in $\mathcal{S}$ is minimized provided the individual rate requirement of each UE is satisfied. This leads to efficient resource allocation for converged multicast and unicast transmissions.

$$\begin{aligned} \mathbb{P} : \min_{\mathcal{T}} \; & R^s = R^u + R^m \\ \textbf{s.t.} \quad & \mathcal{T}_q^u + \mathcal{T}_q^m = 1, \quad \forall\, q \in \mathcal{S}, \\ & D_q^u \cdot \mathcal{T}_q^u + D_q^m \cdot \mathcal{T}_q^m \geq D_q, \quad \forall\, q \in \mathcal{S}. \end{aligned} \tag{4}$$

The objective is to determine the efficient allocation $\mathcal{T}$ that attempts to minimize the total number of RBs (or resources) required to serve all UEs in the system. The first constraint states that a UE can either be served via unicast or multicast transmission mode. Here, $\mathcal{T}_q^u \in \{0,1\}$ denotes UE q is served via 5G unicast cell if $\mathcal{T}_q^u$ = 1 otherwise not. Similarly, $\mathcal{T}_q^m \in \{0,1\}$ denotes UE q is served via 5G multicast-broadcast cell if $\mathcal{T}_q^m$ = 1. The last constraint reflects that the individual rate requirement of each UE is satisfied.

Please note that we treat the UE request to access the content as UE arrival. DY-RUM algorithm (Algorithm 1) is designed to achieve the objective in problem $\mathbb{P}$ upon arrival of a new UE in the system. To achieve an efficient resource allocation, the proposed algorithm (re)distribute existing UEs ($\mathcal{S}$) and the new arrival (with UE ID q') in two disjoint sets, a set of unicast UEs ($\tilde{\mathcal{S}_u}$) and a set of multicast UEs ($\tilde{\mathcal{S}_m}$). DY-RUM algorithm uses a sorted list *A* of all existing UEs for processing, where UEs are sorted based on their R_q^m values. Upon arrival, the new UE (with UE ID q') is inserted in list *A* at the appropriate position (based on its $R_{q'}^m$ value). Let ϕ' be the index of UE q' in list *A*. Note that the UE ID and UE index in list *A* are independent values in $\mathbb{Z}_+$. If $R^m \geq R_{q'}^m$ (or $R_{A[\phi']}^m$), i.e., the number of RBs already allocated (i.e., to serve the UEs in $\mathcal{S}_m$ via multicast transmission) to existing set $\mathcal{S}_m$ is greater than that of the number of RBs required to serve the new UE via multicast transmission, then new UE is served via multicast transmission mode. Thus, the UE allocation that achieves an efficient RB utilization is $\tilde{\mathcal{S}_u} \leftarrow \mathcal{S}_u$ and $\tilde{\mathcal{S}_m} \leftarrow \mathcal{S}_m \cup \{q'\}$ (or $\tilde{\mathcal{S}_m} \leftarrow \mathcal{S}_m \cup \{A[\phi']\}$) (as illustrated in line 6). By $A[\phi']$, we denote the UE stored at index ϕ' in list *A*. Therefore, R^s (the total quantity of radio resource required) remains unchanged even after the inclusion of new UE q' in the system, i.e., serving it.

Please be informed that the algorithm provided in this section pertains to specific content. In a multi-content scenario, the same algorithm is to be used separately for resource allocation (sharing) for each individual content.

However, if $R^m < R_{A[\phi']}^m$, an efficient allocation may require re-assignment of UEs in the unicast $\mathcal{S}_u$ and the multicast $\mathcal{S}_m$ sets. Initially, the new UE $A[\phi']$ (or q') is included in the unicast set $\mathcal{S}_u$. Then, index γ is set to value $|\mathcal{S}_m|$ + 1 in *A* (which indicates that the set of UEs served via multicast transmission appears before the set of UEs served via unicast transmission in list *A*). Next, we check the condition in line 11 iteratively till the last entry in *A*. If the condition is true, then move UEs from the unicast set to the multicast set and serve them via multicast transmission instead of unicast transmission. The algorithm essentially means that if the additional radio resources required to serve a set of UEs via multicast mode is less than the total radio resources required to serve the same set of UEs via unicast mode then all those UEs can more efficiently be served via multicast mode. It also means that any new UE arrival may create the above-mentioned condition and hence trigger the reconfiguration of the two sets, the $\mathcal{S}_m$ and the $\mathcal{S}_u$, i.e., a movement of UEs from $\mathcal{S}_u$ to $\mathcal{S}_m$.

Algorithm 1 DY-RUM

Input: New UE ID q', $\mathcal{S}_u$, $\mathcal{S}_m$, List A
Precondition: Disjoint sets $\mathcal{S}_u$ and $\mathcal{S}_m$ provide an efficient RB utilization s.t. $\mathcal{S} = \mathcal{S}_u \cup \mathcal{S}_m$
Output: Allocation $\mathcal{R}_u$ ($\tilde{\mathcal{S}_u}$), $\mathcal{R}_m$ ($\tilde{\mathcal{S}_m}$) with new UE q'
Insert new UE q' in sorted list A
ϕ' = position of UE q' in A
if $R^m \geq R_{A[\phi']}^m$ **then**
  $\tilde{\mathcal{S}_u} \leftarrow \mathcal{S}_u$ and $\tilde{\mathcal{S}_m} \leftarrow \mathcal{S}_m \cup \{A[\phi']\}$
else
  Update $\mathcal{S}_u \leftarrow \mathcal{S}_u \cup \{A[\phi']\}$
  $\gamma \leftarrow |\mathcal{S}_m| + 1$
  for $\omega = \phi', \ldots, \text{length}[A]$ **do**
    if $R_{A[\omega]}^m - R^m \leq \sum_{\phi=\gamma}^{\omega} R_{A[\phi]}^u$ **then**
      $\mathcal{S}_u \leftarrow \mathcal{S}_u \setminus \{A[\gamma], \ldots, A[\omega]\}$,
      $\mathcal{S}_m \leftarrow \mathcal{S}_m \cup \{A[\gamma], \ldots, A[\omega]\}$
      $R^m \leftarrow R_{A[\omega]}^m$
      $\gamma \leftarrow \omega + 1$
    end if
  end for
  $\tilde{\mathcal{S}_u} \leftarrow \mathcal{S}_u$, $\tilde{\mathcal{S}_m} \leftarrow \mathcal{S}_m$
  Update R^u, R^m, R^s
end if

TABLE II
LIST *A* OF UES

UE Index in $A[\phi]$	1	2	3	4	5	6
UE ID (q)	2	1	5	3	6	4
$R_{A[\phi]}^m$	3	4	5	7	10	14
$R_{A[\phi]}^u$	2	2	2	1	3	1
		$\mathcal{S}_m$			$\mathcal{S}_u$	

We illustrate the DY-RUM algorithm using an example: Consider 6 UEs in the system $\mathcal{S} = \{1, ..., 6\}$, where $q \in \mathcal{S}$ is a unique ID assigned to each UE on arrival. As described in Algorithm 1, UEs are sorted in list *A* in increasing order of R_q^m shown in Table II. As is apparent, the optimal allocation of UEs (in $\mathcal{S}$) is $\mathcal{S}_u = \{3, 6, 4\}$, $\mathcal{S}_m$ = {2, 1, 5} with R^m = 5 and R^u = 5.

TABLE III
UPDATED LIST *A* WITH NEW UE

UE Index in A[ϕ]	1	2	3	4	5	6	7
UE ID (q)	2	1	5	3	7	6	4
$R_{A[\phi]}^m$	3	4	5	7	8	10	14
$R_{A[\phi]}^u$	2	2	2	1	3	3	1
				$\tilde{\mathcal{S}_m}$			$\tilde{\mathcal{S}_u}$

When a new UE with ID 7 arrives, let the RBs required to serve the new UE via multicast and unicast transmission be 8 and 3, respectively. Next, new UE is inserted in list *A* (based on the value of R_q^m) at index ϕ' = 5, as shown in Table III. Since $R_{A[5]}^m > R^m$, the UE with ID 7 cannot be served via a multicast transmission (i.e., by the 5G multicast-broadcast cell) without increasing the required RBs at the 5G multicast-broadcast cell. Therefore, it is not directly added to set $\mathcal{S}_m$ and instead added to set $\mathcal{S}_u$ (lines 5 to 8) initially. This leads to an initial value of R^m = 5, R^u = 5 + 3 = 8 and R^s = 13 RBs. However, this may not be the most efficient resource utilization. To achieve a more efficient resource utilization in the system, the new arrival may require shifting the new UE along with some existing UEs from the set $\mathcal{S}_u$ to $\mathcal{S}_m$. We observe that with the arrival of the new UE, the additional RBs required to serve the UEs at indices 4, 5 and 6 and with IDs {3, 7, 6} in multicast mode is 5 (= 10 - 5) while the number of RBs required to serve the same set of three UEs in unicast mode is 7 (= 1 + 3 + 3). This means that a more efficient resource allocation can be achieved by shifting the three UEs (at indices 4, 5 and 6) from the set $\mathcal{S}_u$ to $\mathcal{S}_m$, i.e., the set $\mathcal{S}_m$ can be expanded to take in additional UEs including the new arrival. It should be noted that the situation for UEs with IDs 3 and 6 changed due to the arrival of the new UE (ID 7). Originally, these UEs were more efficiently served in unicast mode. The decision of shifting of UEs is performed using the for loop at line 10, and hence, list A is traversed from index $\omega = \phi'$ till the end.

In iteration 1, the condition (at line 11) happens to be true (i.e., 8 - 5 $\leq$ (1 + 3)), which implies that RBs required to serve UEs (at $A[4]$ and $A[5]$) can be reduced further if served via 5G multicast-broadcast cell in multicast mode. Hence, $A[4]$ and $A[5]$ (i.e., UEs with IDs 3 and 7) are shifted to $\mathcal{S}_m$. Now, update R^m, γ and ω to 8, 6, and 6, respectively. Next in iteration 2, condition $R^m_{A[6]} - R^m \leq R^u_{A[6]} i.e., 10 - 8 \leq 3$, satisfies. Therefore, $A[6]$ (or UE ID 6) is also shifted to $\mathcal{S}_m$, and R^m = 10 and γ = 7 are updated. In the last iteration, condition 14 $-$10 $\leq$ 1 false and hence $A[7]$ (or UE ID 4) continues to remain in set $\mathcal{S}_u$, to be served via 5G unicast cell in unicast mode as before the arrival of UE ID 7. Thus, we get the most efficient allocation $\tilde{\mathcal{S}_u}$ = {4}, $\tilde{\mathcal{S}_m}$ = {2, 1, 5, 3, 6, 7}) on arrival of UE ID 7 with R^m = 10, R^u = 1 and R^s = 11 (shown in Table III).

We observe from Table II and Table III that the UE with the maximum RB requirement in the multicast set $\mathcal{S}_m$ is always less than that of the UE with the minimum RB requirement in unicast set $\mathcal{S}_u$. We observe from Table II and Table III that the A[ϕ] index of UEs in the multicast set $\mathcal{S}_m$ is always less than that of the UEs in the unicast set $\mathcal{S}_m$.

IV. Simulation Results

In this section, we evaluate the performance of the proposed DY-RUM algorithm through MATLAB simulations. We employ a dedicated 5G multicast-broadcast cell for multicast transmission with a coverage radius of 1000 m alongside multitudinous 5G unicast cells for unicast transmission, each with a coverage radius of 100 m. We examine simulation parameters accordant with the International Telecommunication Union (ITU)'s 5G standard and 3GPP standard [14], [15] and are inventoried in Table IV. Please note that we have assumed omni-directional antennas in the simulation. However, the change to directional antennas should not make any difference. UEs are distributed uniformly across the region. Each UE is connected with 5G unicast and 5G multicast-broadcast cells simultaneously. However, UE can be served either from a 5G unicast cell or a 5G multicast-broadcast cell at any time. Based on the CQI and the data rate requirement of the individual UE, the required number of RBs (for both the unicast and the multicast transmission) to serve the UE is computed in line with the 3GPP 5G standard [11], [12], [13].

TABLE IV
Simulation Parameters [14], [15]

Parameters	Values
Carrier Frequency	4GHz
Number of Multicast Cells	1
UE Distribution	Uniform
5G multicast-broadcast BS (Multicast)	
Coverage Radius	1000m
Transmit Power	46dBm
BS Antenna Height	35m
BS Noise Figure	5dB
BS Antenna Gain	8dBi
Antenna	Omni-directional
5G unicast BS (Unicast)	
Coverage Radius	100m
Transmit Power	41dBm
BS Antenna Height	25m
BS Noise Figure	5dB
BS Antenna Gain	8dBi
Antenna	Omni-directional

The proposed algorithm achieves efficient resource utilization, considering that sufficient resources are available to serve all UEs in the system. The performance of the proposed algorithm is compared against the "unicast-only transmission algorithm" and "multicast-only transmission algorithm", wherein all UEs are served via unicast transmission mode through the 5G unicast cells (in the case of unicast transmission algorithm) while all UEs are served via multicast transmission mode through the 5G multicast-broadcast cell (in case of multicast only transmission algorithm).

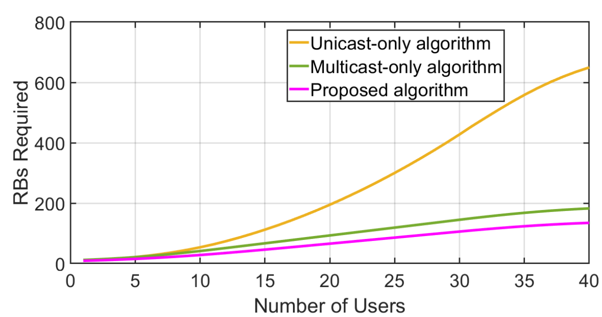

Fig. 2. Resource utilization (RBs required) vs number of users in case of single content scenario.

We consider a scenario where the UE arrival process follows Poisson distribution with an average arrival rate (average content requests rate) β_a = 3 UEs per minute. Each UE has a data rate requirement of D = 3 Mbps. We compare the performance of the DY-RUM algorithm individually with the

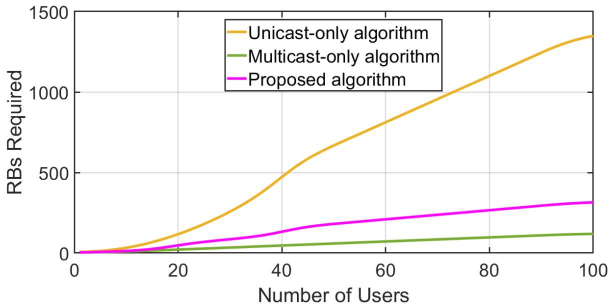

Fig. 3. Resource utilization (RBs required) vs number of users in case of multiple groups (four different groups) scenarios (with each group of users requesting a different content).

unicast and the multicast transmission algorithms, assuming that once a UE with a content request arrives in the system, it stays for the remaining duration of the content streaming. The dynamic UE departure scenario shall be considered in our future work. In Figure 2, we observe that the proposed algorithm outperforms both unicast and multicast transmission algorithms regarding RB requirement. The unicast algorithm is the worst in terms of RB requirement, as it allocates dedicated RBs to each UE requesting the same content. The reason behind poor performance in multicast algorithms is that in multicast transmission, the required number of RBs depends on the worst channel condition experienced by the UE in the multicast-broadcast cell. However, the DY-RUM algorithm provides an efficient resource utilization by splitting the UEs across 5G unicast and 5G multicast-broadcast cells based on the channel condition experienced under both unicast and multicast-broadcast cells. Thus, UEs with poor channel conditions for multicast transmission are served via 5G unicast cells (in unicast mode) bringing efficiency.

Figure 3 presents the performance results for the scenario when there are multiple groups of UEs, with each individual group requesting a different content. Here, we also assume the dynamic arrival of UEs and UEs are assumed to be evenly distributed among the groups. For the simulation scenario, we have considered four different groups of UEs. Figure 3 illustrates that the proposed algorithm outperforms unicast and multicast transmission algorithms. The unicast algorithm exhibits the poorest performance, utilizing a significantly higher quantity of radio resources than the proposed algorithm. Similarly, the multicast transmission algorithm also performs poorly as compared to the proposed DY-RUM algorithm.

V. Conclusion and Future Work

This paper presents a novel dynamic resource allocation algorithm for a converged unicast and multicast (DY-RUM) transmission in 5G and beyond. We propose the algorithm in the context of O-RAN architecture and suggest employing O-RAN RIC to control and manage the resource allocation in radio access networks and also to decide the data transmission modes (unicast or multicast) for individual UEs. We compare the performance of the proposed DY-RUM scheme with unicast-only and multicast-only transmission schemes and observe that the DY-RUM outperforms both these transmission schemes. This work focuses on efficient resource utilization while ensuring the required QoS to UEs. As a prospective expansion of this research, we aim to incorporate dynamic UE departure and simultaneous arrival-departure scenarios in the algorithm in our future work. We think the algorithm is optimal and aim to provide proof of the optimality of the DY-RUM algorithm in a later work. We also aim to investigate scenarios with constraints on the amount of radio resources available for transmission in each mode. We also intend to incorporate the impact of change in radio condition of individual UEs due to mobility.

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