Joint Device-to-Device and MBSFN Transmission for eMBB Service Delivery in 5G NR Networks

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Abstract. Next to come 5G New Radio (NR) radio access technology is foreseen to support a massive number of "resource-hungry" connections and provide high-quality services. Multimedia Broadcast/Multicast Service over Single Frequency Network (MBSFN) for NR, expected in forthcoming 3GPP releases, will enable the simultaneous delivery of the same content over the multiple 5G cells synchronized in time. In this paper, we show that Device-to-Device (D2D) communications can improve the MBSFN network coverage, data rate, and latency for the future 5G use cases. More specifically, we propose a new D2D-aided MBSFN area formation algorithm, which foresees that in such an area the content can be delivered through either MBSFN or D2D transmissions. Achieved simulation results testify that our proposed algorithm is able to improve the system Aggregate Data Rate (ADR) and, at the same time, to satisfy the user's requirements.

Keywords: 5G · eMBB · Dynamic MBSFN Area formation · D2D

1 Introduction

The fifth-generation (5G) radio access technology, named as "New Radio" (NR), enables the provision of innovative advanced services [1].

A primary service classification includes three macro-categories. *Enhanced Mobile Broadband (eMBB)* supports larger data volume and higher data rate than today's mobile broadband services. *Massive Machine Type Communications (mMTC)* focus on the support of low energy consuming connections among

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a huge number of low-cost, low-power, and long-life devices. *Ultra-Reliable and Low-Latency Communications (URLLC)* allow a bidirectional communication among devices requiring low latency and high network reliability. From the combination of the above categories, further use cases can be obtained. As an example, virtual augmented reality can be seen as the fusion of eMBB and URLLC.

Moreover, the exponential growth in the number of devices requesting new services requires that TELCO operators jointly face several challenges, such as radio resource management, network scalability, and flexibility [2].

On one hand, an interesting means to boost the system capacity and to improve users' perceived video quality in 5G NR networks is Device-to-Device (D2D) communications [3]. Indeed, D2D guarantees that high-performing links are set up among users in mutual proximity. On the other hand, to satisfy the ever-demanding requests for resource-hungry applications and to guarantee the network scalability, in forthcoming 3GPP releases, the 5G NR technology is expected to provide eMBB services in single frequency mode by supporting Multimedia Broadcast/Multicast Service over Single Frequency Network (MBSFN) [4]. Thanks to the MBSFN protocol, adjacent cells (i.e., gNB) of a MBSFN Area are synchronized in time to perform the so-called MBSFN transmission [5], that is a simulcast technique for the delivery of the same service over the same radio resources.

The solution traditionally utilized for the MBSFN Area formation follows a fixed approach where coordinated gNBs deliver the same eMBB content to all the interested users with the most robust modulation and coding scheme. As a consequence, the system performance is negatively affected by users experiencing adverse channel conditions. To overcome the limitations of the static approach, authors in [6,7] proposed a dynamic MBSFN Area formation, known as Single Content Fusion (SCF), where users experiencing good channel qualities are served through the MBSFN Area while users with poor channel conditions are served via unicast links. As defined in the Long Term Evolution (LTE) Release 11 [8], SCF foresees a fixed radio resource allocation, where up to 60% of the available radio resources are allocated for multicast/broadcast transmissions, and the remaining 40% for unicast connections. To better understand which radio resources SCF allocates to the unicast users kept out of the MBSFN Area, in [9] a performance evaluation has been done for two cases: *in-band*, where unicast users left out of the MBSFN Area exploit the radio resources allocated to the MBSFN transmission; and, *out-band*, where unicast users excluded from the MBSFN transmission exploit the radio resources destined to the unicast traffic in background.

In the 3GPP Release 15 [4], the 5G technology supports the coexistence of multicast/broadcast and unicast services by allowing for both static and dynamic radio resource allocation. Moreover, 5G foresees that up to 100% of available radio resource can be allocated for the multicast/broadcast service delivery.

In this paper, we propose a novel algorithm for the dynamic formation of MBSFN Area assisted by D2D communications, hereinafter referred to as D2D-MBSFN scheme, which is aimed at boosting the system aggregate data rate (ADR) under the constraint to satisfy all UEs' requests. We compare our proposed algorithm with the SCF scheme through extensive simulation campaigns.

The rest of the paper is organized as follows. Background and motivations of our work are reported in Sect. 2. Section 3 describes our proposed D2D-aided MBSFN area formation algorithm. Simulations and results of the performance analysis are discussed in Sect. 5. Conclusive remarks are given in the last section.

2 Background and Motivations

Evolved-Multimedia Broadcast and Multicast Services (eMBMS) is an evolution of the broadcast technology for the cellular systems. It was designed to provide broadband services over a single cell via Single-Cell Point-to-Multipoint (SC-PTM) connections or over multiple cells arranged to perform a MBSFN transmission.

MBSFN related data and signalling traffic are carried in dedicated logical, transport, and physical channels. Counting procedure allows the network to choose between unicast and MBSFN transmission modes according to the number of UEs interested in MBMS service. In 3GPP Release 13, SC-PTM transmission mode was introduced to broadcast MBMS data on a per-cell basis with the aim of improving network spectral efficiency.

The eMBMS architecture is based on two main logical entities. The *Broadcast/Multicast Service Center* (BM-SC) supports various eMBMS user services, sets up the eMBMS session and initiates content delivery, and the *MBMS Gateway* MBMS-GW forwards MBMS traffic to the downstream nodes using IP multicast distribution. To enable broadcasting and multicasting in the forthcoming 5G system, the 5G-Xcast project [10] proposes three possible architectures, where the BM-SC and MBMS-GW are split into control plane function (CXF) and user plane function (UXF) [11].

One of the main issues for multicast/broadcast service delivery concerns the choice of transmission parameters. There are different Radio Resource Management (RRM) techniques to determine the transmission parameters for the group-based communications. The Conventional Multicast Scheme (CMS) and the Opportunistic Multicast Scheme (OMS) are both single-rate approaches. The main idea of CMS is to broadcast the content to all relevant UEs with the lowest modulation and coding scheme (MCS). It guarantees that all UEs will be able to decode the transmission but at the expense of the poor network spectral efficiency. In OMS the data transmission is scheduled each Transmission Time Interval (TTI) only to the set of UEs with the best channel conditions. OMS achieves long-term fairness but suffers from short-term unfairness. Multicast Subgrouping (MS) is a multi-rate approach which splits UEs into several subgroups with different MCSs. MS offers a good trade-off between fairness and throughput.

The problem of MBSFN Area Formation relates to the issues on how to group eMBMS-enabled cells and how to broadcast the content.

The SCF scheme provides a dynamic method for MBSFN Areas formation based on the content preferences. First, SCF creates single-content MBSFN areas by grouping cells with similar content interests. Then, it merges the overlapping single-content MBSFN areas into multi-content MBSFN areas to maximize the overall throughput. In detail, SCF chooses a better MCS level for the MBSFN transmission and serves the users with poor channel conditions via unicast link.

3 The Proposed D2D-Aided MBSFN Area Formation Algorithm

The idea of D2D-MBSFN scheme is to exploit both MBSFN and D2D transmissions to improve the system performance and the Quality of User Experience (QoE). The algorithm consists of the following steps:

1. *Channel Status Indicator (CSI) collection*. All users send their channel status feedback to the gNBs.
2. *MBSFN Configuration*. Based on the collected CSI, the gNB selects the appropriate transmission parameters, i.e, the lowest supported MCS (the most robust modulation).
3. *D2D configuration*. The gNB iteratively increases the MCS level of the multicast transmission. If all UEs in the area support the selected MCS, the eMBB content will be delivered through the MBSFN Area; otherwise, it will be delivered by means of the D2D communications towards the out-of-service UEs. All relevant gNBs select appropriate forwarding nodes (FNs) among the UEs in the MBSFN Area and verify if all the out-of-service UEs are reached by the FNs via D2D links.

The algorithm stops either when at least one UE is not able to receive the eMBB service or when the ADR after n iterations is lower than the ADR after the $n-1$ iterations. Figure 1 shows how the proposed algorithm works.

4 System Model

We consider a 5G NR system and MBSFN network where all gNBs are synchronized in time and simultaneously transmit data over the same frequency. Transmissions are scheduled in frames, each of which consists of 10 subframes. A subframe of 1 ms can be composed of a different number of slots according to the NR numerology [12]. The radio spectrum is managed in terms of Resource Blocks (RBs). One RB comprises 12 consecutive subcarriers. NR numerology also supports different subcarrier spacings. UEs are interested in an eMBB service, e.g. Video on Demand (VoD). Therefore, for the wideband service like VoD, we consider the numerology $\mu = 0$ with SCS of 15 KHz and TTI of 1 ms.

Let $\mathcal{C}$ denote a set of gNBs deployed inside the Synchronization Area, which may include one or more MBSFN Areas. All MBSFN Areas belong to a set $\mathcal{M}$.

The content can be delivered towards UEs in two modes: *(i) cellular mode*, when UEs receive data directly from the gNB, and *(ii) D2D mode*, when UEs receive data via D2D links from the forwarding UE. Let $\mathcal{U}$ be a set of UEs receiving the service through the MBSFN transmission. We denote $\mathcal{D}$ as a set of UEs served by D2D communications and $\mathcal{R}$ as a set of D2D-relays.

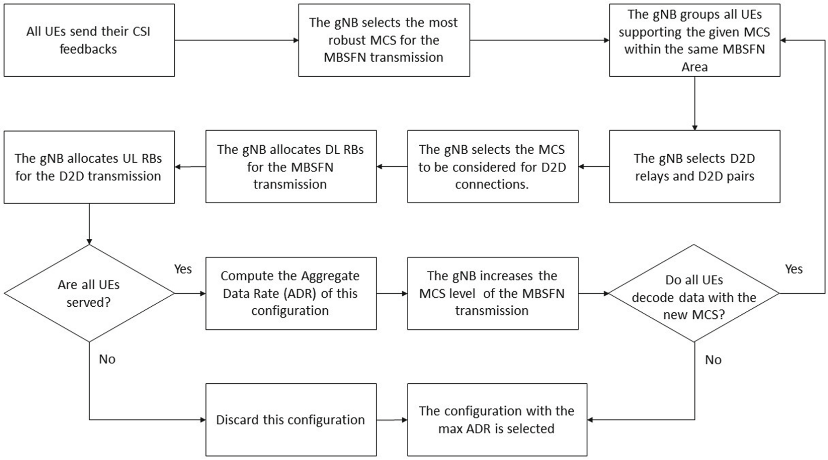

Fig. 1. Flowchart of the proposed D2D-aided MBSFN area formation algorithm.

Each gNB collects the CSI of all devices within the area and selects such an MSC to satisfy all UEs. A scheduler allocates radio resources every TTI. Let $\mathcal{RB}_m$ stand for the set of available RBs for the MBSFN Area $m \in \mathcal{M}$, while $\mathcal{RB}_{b,m}$ and $\mathcal{RB}_{D2D,m}$ correspond to the sets of dedicated RBs to the MBSFN and D2D transmissions, respectively.

We consider that D2D communications take place in uplink subframes in order to exploit unused radio resources. Thus, the number of RBs allocated to D2D communications must be less or equal to the number of available RBs in a given MBSFN Area:

$$| \mathcal{RB}_{D2D,m} | \leq | \mathcal{RB}_m^{\mathrm{UL}} |, \quad \forall m \in \mathcal{M} \tag{1}$$

The overall ADR of MBSFN transmission is a sum of individual rates of the UEs from the set $\mathcal{U}$ with the respect to the number of allocated RBs:

$$\mathcal{ADR}_{B,m} = \sum_{u \in \mathcal{U}} Rate(\mathcal{U}) \times | \mathcal{RB}_{b,m} |, \forall m \in \mathcal{M} \tag{2}$$

In a similar way, we define the overall ADR of D2D connections:

$$\mathcal{ADR}_{D2D,m} = \sum_{u \in \mathcal{D}} Rate(\mathcal{D}) \times | \mathcal{RB}_{D2D,m} |, \forall m \in \mathcal{M} \tag{3}$$

Finally, the ADR over all MBSFN Areas is given by:

$$\mathcal{ADR} = \sum_{m \in \mathcal{M}} \left(\mathcal{ADR}_{B,m} + \mathcal{ADR}_{D2D,m} \right) \tag{4}$$

MBSFN Area formation problem for the D2D-MBSFN algorithm can be formulated as:

$$\begin{gathered} \arg\max_{\mathcal{RB}} \mathcal{ADR} \\ \text{subject to} (1), (4) \end{gathered} \tag{5}$$

and heuristically solved under the condition that all UEs will receive the broadcast content.

5 Performance Analysis

Simulative campaigns have been carried out by means of the MATLAB tool. MATLAB is a programming software featured by a matrix-based language used for designing algorithms and models, and for analyzing data of a wide range of applications (i.e., deep learning and machine learning, signal processing and communications, image and video processing, control systems, test and measurement, computational finance, and computational biology).

To assess the effectiveness of our proposed D2D-MBSFN scheme, we compare it with one of the schemes in the literature, namely SCF. We consider 10 cells within the synchronization area [5] and analyze the performance of the proposed D2D-MBSFN algorithm under two scenarios:

- *Scenario 1.* The number of users per cell is set to 500, while the channel bandwidth varies from 3 to 20 MHz.
- *Scenario 2.* The channel bandwidth is fixed to 10 MHz and the number of users per cell varies from 200 to 600.

UEs are randomly deployed in a cell. We consider a 2 GHz carrier frequency and we set the numerology $\mu = 0$ and the subcarrier spacing equals to 15 kHz. The rest of simulation settings are reported in Table 1.

The percentage of radio resource assigned to the MBSFN transmission is set to 60% (i.e., 60 RBs of the available 100 RBs in the case of a channel bandwidth of 20 MHz) in order to perform a fair comparison between D2D-MBSFN and SCF. We assume that both SCF and the proposed D2D-MBSFN algorithm operate in in-band mode. According to SCF, the considered 60% of the available RBs are split between the MBSFN and unicast transmissions (i.e., again 60% and 40%, respectively). D2D-MBSFN performs the MBSFN transmission during the downlink subframes, and the D2D communications during the uplink subframes by exploiting all 60% of the available RBs for both MBSFN and D2D.

Each simulation has been run several times to achieve the most reliable results with 95% confidence intervals.

The system performance has been evaluated in terms of the following metrics:

- *Aggregate Data Rate (ADR)* is the sum of UEs data rates.
- *Spectral Efficiency* is the data rate normalized by the bandwidth.
- *Average Throughput* is the average data rate experienced by all users.

Figure 2 shows the ADR for D2D-MBSFN and SCF algorithms when the number of UEs per cell is set to 500 and the channel bandwidth varies from 3 to 20 MHz. D2D-aided MBSFN algorithm significantly outperforms SCF at each bandwidth configuration. As expected, both algorithms improve ADR when the channel bandwidth gets wider. Indeed, D2D-MBSFN and SCF increase the ADR from 3.94 Gbps to 34.25 Gbps and from 1.38 Gbps to 20.3 Gbps, respectively.

Table 1. Main simulation assumptions

Parameter	Value
Cell layout	Hexagonal grid, 10 cells
Inter Site Distance	500 m
Pathloss model	$128.1 + 37.6\ log_{10}(\text{R})$, R in kilometers
gNB transmit power	46 dBm
D2D node Tx power	23 dBm
gNB antenna gain	15 dBi
UE antenna gain	0 dBi
gNB noise figure	5 dB
UE noise figure	9 dB
Carrier frequency	2 GHz
Scheduling Frame	10 ms
RB size	12 sub-carrier
μ	0
Sub-carrier spacing	15 kHz
TTI	1 ms
BLER target	1%

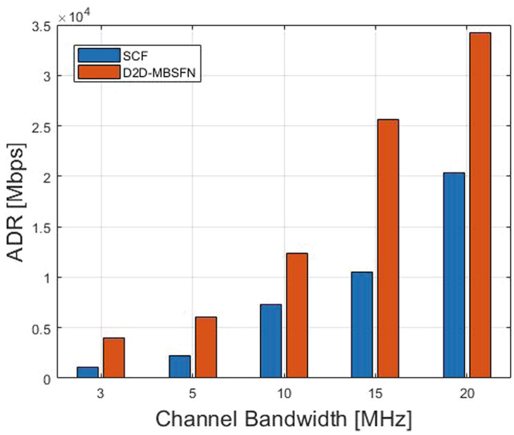

Fig. 2. Aggregate Data Rate under varying channel bandwidth.

However, as we can see in Fig. 3 when both SCF and D2D-MBSFN utilize the same bandwidth but the number of UEs per cell less than 400, the ADR in case of SCF scheme is higher than that of our proposal. It is because the higher the number of UEs, the higher the probability to find users with poorest channel conditions. Due to the cumulative nature of ADR, the metric, in general, is increasing together with the increasing number of UEs per cell.

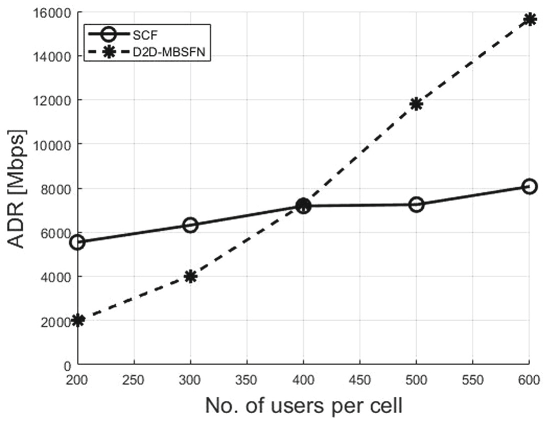

Fig. 3. Aggregate Data Rate under varying number of UEs.

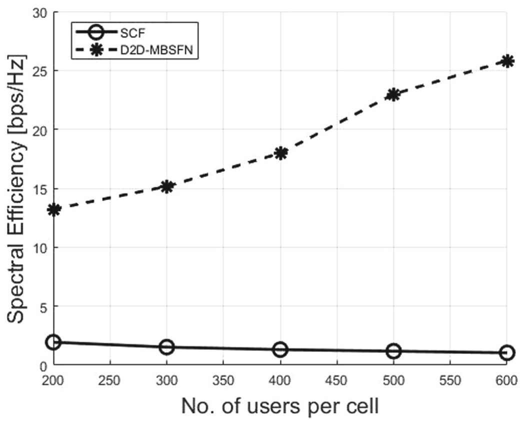

Fig. 4. Spectral Efficiency under varying number of UEs.

In Fig. 4, the spectral efficiency is evaluated in the case of simulation scenario 2. As the number of UEs increases from 200 to 600, the spectral efficiency of D2D-MBSFN significantly grows since less robust MCSs can be utilized for serving MBSFN users. In fact, UEs in bad conditions are served via D2D communications which, in addition, can take advantage over the utilization of all available RBs. On the contrary, the performance of SCF worsens under an increasing number of users since the presence of a higher number of UEs perceiving bad channel qualities forces the selection of more robust MCSs. As a result, the spectral efficiency is considerably (on average 15-fold) higher for our proposed D2D-MBSFN algorithm with respect to SCF.

As shown in Fig. 5, D2D-MBSFN considerably improves the spectral efficiency with respect to SCF in the simulation scenario 1 as well.

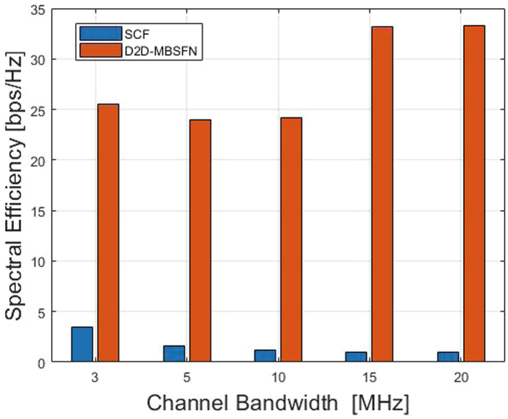

Fig. 5. Spectral Efficiency under varying channel bandwidth.

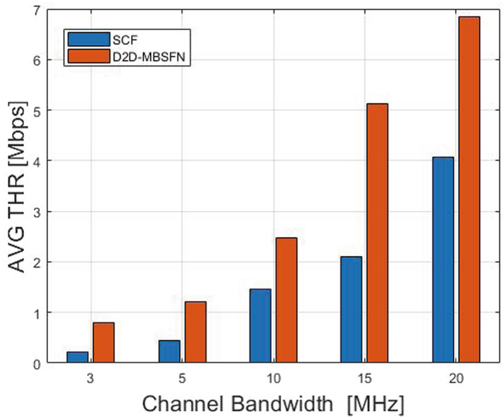

Fig. 6. Throughput under varying channel bandwidth.

In D2D-MBSFN, cell edge UEs benefit from the D2D transmissions in single frequency mode with respect to the unicast connections in SCF. The data rates of such UEs significantly increase leveraging high performing D2D links, Fig. 6. The average data rate of UEs exploiting SCF drops as the number of UEs per cell increases (see Fig. 7) while the metric continues to grow even when more devices are served through the D2D connections.

6 Conclusions

In this paper, we proposed a novel MBSFN area formation algorithm assisted by D2D communications that aim at improving the system Aggregated Data Rate and the system spectral efficiency thanks to the establishment of connections

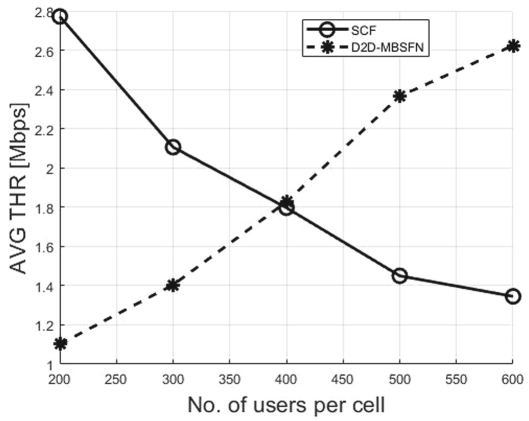

Fig. 7. Throughput under varying number of users per cell.

between nodes in proximity. It selects the best MBSFN Area configuration under the condition to satisfy the user's requirements. By choosing a proper MCS for MBSFN transmissions and more performing direct links between MBSFN UEs and edge UEs, the proposed approach is able to boost the average throughput. Simulation results show that the D2D-MBSFN scheme considerably outperforms the reference SCF scheme in several test conditions.

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