Power Allocation for Layered Multicast Video Streaming in Non-Orthogonal Multiple Access System

DOI:

[10.1109/GLOCOMW.2017.8269084](https://doi.org/10.1109/GLOCOMW.2017.8269084)

Document Version

Accepted author manuscript

[Link to publication record in Manchester Research Explorer](#)

Citation for published version (APA):

Pehin Dato Haji Dani, M. N., Al-Abbasi, Z., & So, D. K. C. (2018). Power Allocation for Layered Multicast Video Streaming in Non-Orthogonal Multiple Access System. In *IEEE Globecom*
<https://doi.org/10.1109/GLOCOMW.2017.8269084>

Published in:

IEEE Globecom

Citing this paper

Please note that where the full-text provided on Manchester Research Explorer is the Author Accepted Manuscript or Proof version this may differ from the final Published version. If citing, it is advised that you check and use the publisher's definitive version.

General rights

Copyright and moral rights for the publications made accessible in the Research Explorer are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

Takedown policy

If you believe that this document breaches copyright please refer to the University of Manchester's Takedown Procedures [<http://man.ac.uk/04Y6Bo>] or contact uml.scholarlycommunications@manchester.ac.uk providing relevant details, so we can investigate your claim.

Power Allocation for Layered Multicast Video Streaming in Non-Orthogonal Multiple Access System

Muhammad Norfauzi Dani, Ziad Qais Al-Abbasi and Daniel K.C. So

School of Electrical and Electronic Engineering

The University of Manchester, United Kingdom

Email: norfauzi.dani@postgrad.manchester.ac.uk, ziad.al-abbasi@manchester.ac.uk and d.so@manchester.ac.uk

Abstract—Non-orthogonal multiple access (NOMA) scheme is emerging as an enabling technology for 5G wireless networks, which address the growing demand for capacity that is mostly made up of high quality video content. In this paper, by combining the principles of NOMA and layered coding, the sum rate is enhanced for multicast video streaming. An optimization problem for power allocation is formulated to maximize the overall sum rate whilst achieving the total transmission power constraints and target rates. A near-optimal scheme and a low-complexity closed form solution are proposed. Numerical simulation results show that the proposed schemes offer better sum rate performance than the existing schemes. The closed form solution incurs performance degradation relative to the near-optimal solution but with a much lower complexity. Furthermore, the proposed schemes provide a superior degree of fairness towards the users with poor channel conditions.

Index Terms—Non-Orthogonal Multiple Access (NOMA), power allocation, multicast, sum rate maximization

I. INTRODUCTION

THE International Telecommunication Union (ITU) estimated that the global mobile cellular subscriptions have reached the 3.6 billion figures by the end of 2016 and will be expected to rise to 9 billion by 2021 [1]. The tremendous growth in the number of users inevitably contributes to the steady increase in data traffic. Nevertheless, the upsurge in the data traffic will be more significant due to the shift of users' trends from being connection-centric (e.g. voice and text messages) to content-centric (e.g. video streaming, video on demand and IPTV). The basis can be found in a study in [2], which states that more than half of mobile data traffic is contributed by video since 2015. This figure will be expected to grow rapidly in the future prompting the need for thousand-fold increase in capacity and hence wireless resources. In efforts to address the capacity and data rates challenges, innovative solutions have been explored which include massive MIMO, network densification and advanced multiple access schemes [3].

Non-orthogonal multiple access (NOMA) has emerged as one of the promising technology which significantly improves spectral efficiency, increases cell-edge transmission rate and offers low latency [4]–[6]. In addition, the study in [5] has shown that the overall throughput of NOMA in macrocell environment improves by more than 30 percent as compared to the existing orthogonal multiple access scheme and further

gains are anticipated with the application of advanced power allocation scheme. Therefore NOMA is being considered as one of the candidate multiple access schemes for 5G wireless networks [3].

Multicasting is a technology which offers high efficiency in the utilization of available resources particularly in the delivery of multimedia content. When multiple users in the same cell request for the same content, multicasting technique allows the base station to deliver the content simultaneously on shared allocated resources. Therefore, the limited spectral resources are utilized efficiently while significantly reducing the transmission power at the base station. The resource allocation for OFDMA based multicast system has been intensively studied in literature as highlighted in a survey in [7]. In conventional multicasting, the data rate is often constrained by the user with the worst channel quality to ensure all users in a particular multicast group are able to decode the content with minimal errors.

Recent works, such as in [8], focus on multi-rate multicast techniques in which user grouping and content splitting via layered coding are performed to allow each user to receive data streams based on the handling capacities. In layered coding such as Multiple Description Coding (MDC) [9], Fine Granularity Scalable (FGS) coding [10] and Scalable Video Coding (SVC) [11], the content is encoded into multiple independent data streams of different transmission rates and the quality of the content improves with better channel conditions as more layered streams are successfully decoded by the users. For the case of OFDMA network, each stream is transmitted on different subcarrier or resource block (RB) and hence is less efficient in terms of resource utilization. In NOMA, the allocated resource can be efficiently utilized by exploiting the power-domain multiplexing.

As the studies on resource allocation in unicast NOMA system have already attracted much attention such as in [5], [12]–[15], the application of NOMA in multicast network is still in its early stage. Other works related to NOMA-based multicast system includes the investigation of the optimal beamforming vectors in multicast beamforming NOMA system which is aimed to achieve minimum transmission power and specified target rates [8]. Meanwhile, the authors in [16] and [17] apply NOMA to multicast cognitive radio networks and evaluate its performance in terms of outage probability and diversity order.

In this paper, we exploit the nature of NOMA and layered coding to enhance the sum rate for video multicasting. In NOMA, the stronger users detect the weaker users' signal first and cancel them from the received signal for their own signal detection [15]. Applying NOMA for video multicasting with layered coding, the weak users' signal can be the base layer (containing the low quality video content), while the strong users are sent the enhancement layers (the additional information to improve video quality). Therefore, instead of discarding the weak users' signal, the strong users will also use it to increase the sum rate. In this work, we aim to optimize the sum rate of this system by power allocation. The optimization problem can be solved optimally by using numerical tools with extremely high complexity. We present power allocation schemes based on near-optimal subgradient method and low-complexity closed form solution to achieve the performance close to the optimal solution.

The remainder of this paper is organized as follows. Section II describes the system model of the NOMA-based multicast network. Section III presents the formulation of the optimization problem as well as the optimal and sub-optimal power allocation schemes. Simulation results to verify the performance of the proposed allocation schemes are presented in Section IV. Finally, Section V concludes the paper.

II. SYSTEM MODEL

We consider a downlink NOMA-based network with a base station (BS) that serves a group of K multicast users who request for the same video content¹ as illustrated in Fig. 1. The BS delivers the content at a total transmit power of P_T over a total system bandwidth of B_T which is divided into N RBs of equal bandwidth B . The bandwidth B is assumed to be smaller than the coherent bandwidth such that each individual RB will experience flat fading. However, the overall channel is assumed to experience independent and identically distributed (i.i.d.) frequency selective fading. Let $\mathcal{K} = \{1, 2, \dots, K\}$ denote the set of all users in the multicast group which are divided into two subgroups $\mathcal{G}_1$ and $\mathcal{G}_2$. Assuming that the BS has the full knowledge of the channel state information (CSI), the users are grouped according to their channel gains $|h_{k,n}|^2$ such that the users with poor channel gain belongs to subgroup $\mathcal{G}_1$ and the strong channel gain users join subgroup $\mathcal{G}_2$. The number of users in each subgroups $\mathcal{G}_1$ and $\mathcal{G}_2$ are represented as K_1 and K_2 respectively. Note that, the channel gain for the k^{th} user at n^{th} RB $|h_{k,n}|^2 = \frac{\xi |H_{k,n}|^2}{PL}$ includes the log-normal shadowing factor ξ , the effect of fading $|H_{k,n}|^2$, and the path loss PL .

The video content is encoded into two data streams via layered coding. The base layer stream X^b consists of the essential data elements of the content and therefore each user will only be able to obtain the desired content if the base layer stream is successfully decoded. Whereas, the enhancement layer stream X^e improves the quality of the content. Based on NOMA scheme, these two data streams are multiplexed in

¹Note that there can be other users in the cell requesting for other contents, which can be served by using other RBs. To focus on the considered problem, we assume there are no other users in this paper.

Figure 1. System model

the power domain at the BS and the signal received by user k at RB n is denoted by

$$Y_{k,n} = h_{k,n} \left(\sqrt{P_n^b} X_n^b + \sqrt{P_n^e} X_n^e \right) + W_k \quad (1)$$

where P_n^b and P_n^e are the power allocated to the base and enhancement layers respectively on each RB n , and W_k is the additive white Gaussian noise. From (1), it can be observed that all the users will receive both base and enhancement layer data streams. Nevertheless, this does not guarantee that each user can successfully decode the data streams, particularly the enhancement layer.

The base and enhancement layer data streams are extracted from the received signal through successive interference cancellation (SIC) technique as shown in Fig. 2. The users in subgroup $\mathcal{G}_1$ directly decodes the mandatory base layer streams by treating the enhancement layer signal as noise. This is possible by ensuring the power allocated to the base layer streams is sufficiently large relative to the enhancement layer signal. Considering the weak channel conditions of the users in subgroup $\mathcal{G}_1$ as well as the low power allocated to the enhancement layer streams, these users will not be able to decode the enhancement layer data. Therefore, the process of extracting the enhancement layer is discarded and the demand of the users in subgroup $\mathcal{G}_1$ is satisfied with the delivery of the base layer stream albeit the low quality content. On the other hand, the receivers of the users in subgroup $\mathcal{G}_2$ will be able to decode the base layer stream and consequently recover the enhancement layer data through the cancellation of the base layer component, which is treated as interference. Hence, these users are able to acquire the high quality content.

In order to ensure that all users successfully decode the base layer, the achievable rate of the base layer stream is constrained by the least channel gain user in the multicast group and hence, is expressed as

$$R^b = \sum_{n=1}^N B \log_2 \left(1 + \frac{P_n^b \gamma_n^b}{P_n^e \gamma_n^b + B N_0} \right) \quad (2)$$

where N_0 is the noise power spectral density and γ_n^b is the

Figure 2. Successive interference cancellation in multicast users' receivers

channel gain of the weakest user in the multicast group which is given by $\gamma_n^b = \min |h_{k,n}|^2$ in which $k \in \mathcal{K}$. Meanwhile, the achievable rate of the enhancement layer stream considers the worst channel quality within subgroup $\mathcal{G}_2$ by taking $\gamma_n^e = \min |h_{k,n}|^2$ where $k \in \mathcal{G}_2$ and thus, is given by

$$R^e = \sum_{n=1}^N B \log_2 \left(1 + \frac{P_n^e \gamma_n^e}{BN_0} \right). \quad (3)$$

It could be noted that, from (2) and (3), the power allocated to the base and enhancement layer streams directly affects the achievable data rate and therefore the overall throughput can be maximized and fairness can be attained by controlling the power allocation ratio, P^b/P^e . From (2), the rate of the base layer stream is restricted by the channel gain of the weakest user and high achievable rate can only be attained by the allocation of large power difference between both layer streams. It is crucial to maintain considerably high rate for the base layer stream as it contain the essential elements of the content which must be received by all multicast users. The achievable data rate of the users in subgroups $\mathcal{G}_1$ and $\mathcal{G}_2$ is respectively given by

$$R_{k_1} = R^b, \text{ for } k_1 \in \mathcal{G}_1 \quad (4)$$

$$R_{k_2} = R^b + R^e, \text{ for } k_2 \in \mathcal{G}_2. \quad (5)$$

III. PROBLEM FORMULATION AND PROPOSED POWER ALLOCATION SCHEMES

The objective of this work is to develop power allocation schemes which are aimed towards maximizing the sum rate of the NOMA multicast system while satisfying a set of constraints. Taking into account that all multicast users K successfully decode the base layer streams and only the members of subgroup $\mathcal{G}_2$ are able to decode the enhancement layer data streams, the sum rate rate of the NOMA multicast system can be expressed as

$$R_{sum} = K \sum_{n=1}^N B \log_2 (1 + \beta_n^b) + K_2 \sum_{n=1}^N B \log_2 (1 + \beta_n^e) \quad (6)$$

where β_n^b is the minimum SINR which guarantee successful decoding of the base layer streams by all users and β_n^e is the minimum SINR which enable all users in subgroup $\mathcal{G}_2$ to decode the enhancement layer streams. Both β_n^b and β_n^e are respectively the SINR expressions of (2) and (3)

$$\beta_n^b = \frac{P_n^b \gamma_n^b}{P_n^e \gamma_n^b + BN_0} \quad (7)$$

$$\beta_n^e = \frac{P_n^e \gamma_n^e}{BN_0}. \quad (8)$$

The optimization problem can be formulated as

$$\underset{P_n^b, P_n^e}{\text{maximize}} \quad R_{sum} \quad (9a)$$

$$\text{subject to} \quad \sum_{n=1}^N P_n^b + \sum_{n=1}^N P_n^e \leq P_T \quad (9b)$$

$$P_n^b \geq 0, P_n^e \geq 0, \forall n \quad (9c)$$

$$R^b : R^e = \Phi_{min}^b : \Phi_{min}^e \quad (9d)$$

where constraints (9b) and (9c) ensures the sum of the allocated power does not exceed the total transmission power P_T and the values of the power allocated to both layer streams on each RB are non-negative. Whereas, constraint (9d) guarantees that base and enhancement layer streams achieve the minimum target rates Φ_{min}^b and Φ_{min}^e respectively whilst maintaining fairness in terms of throughput for both layer streams.

The Lagrangian function of the optimization problem (9a), by taking into account the constraints (9b)-(9d), is expressed as

$$\begin{aligned} L(P_n^b, P_n^e, \mu, \tau) = & K \sum_{n=1}^N B \log_2 (1 + \beta_n^b) \\ & + K_2 \sum_{n=1}^N B \log_2 (1 + \beta_n^e) - \mu \left(\sum_{n=1}^N P_n^b + \sum_{n=1}^N P_n^e - P_T \right) \\ & - \tau \left(\frac{\sum_{n=1}^N B \log_2 (1 + \beta_n^b)}{\Phi_{min}^b} - \frac{\sum_{n=1}^N B \log_2 (1 + \beta_n^e)}{\Phi_{min}^e} \right) \end{aligned} \quad (10)$$

where μ and τ represent the Lagrange multipliers. To solve the optimization problem (9a), we obtain the Karush-Kuhn-Tucker (KKT) conditions as follows

$$\frac{dL}{dP_n^b} = \sum_{n=1}^N \left[\left(K - \frac{\tau}{\Phi_{min}^b} \right) \frac{B}{\ln 2} \left(\frac{\beta_n^b}{P_n^b (1 + \beta_n^b)} \right) \right] - \mu = 0 \quad (11)$$

$$\begin{aligned} \frac{dL}{dP_n^e} = & \sum_{n=1}^N \left(K - \frac{\tau}{\Phi_{min}^b} \right) \frac{B}{\ln 2} \left(\frac{-(\beta_n^b)^2}{P_n^b (1 + \beta_n^b)} \right) \\ & + \left(K_2 + \frac{\tau}{\Phi_{min}^e} \right) \frac{B}{\ln 2} \left(\frac{\beta_n^e}{P_n^e (1 + \beta_n^e)} \right) - \mu = 0 \end{aligned} \quad (12)$$

$$\mu \left(\sum_{n=1}^N P_n^b + \sum_{n=1}^N P_n^e - P_T \right) = 0 \quad (13)$$

$$\tau \left(\frac{\sum_{n=1}^N B \log_2 (1 + \beta_n^b)}{\Phi_{min}^b} - \frac{\sum_{n=1}^N B \log_2 (1 + \beta_n^e)}{\Phi_{min}^e} \right) = 0. \quad (14)$$

A. Optimal Solutions

A computationally intensive numerical tool is required to obtain the optimal solution for problem (9a). The optimization methods in [18] can be used to obtain the optimal power allocations but with very high complexity. In the next section, we propose the use of subgradient method to obtain near-optimal solution at a lower computational complexity.

B. Subgradient Method

From the KKT conditions (11) and (12), the power allocation for both base and enhancement layer streams at each RB n can be derived as

$$P_n^b = \left[(K\Phi_{min}^b - \tau) \left(\frac{1}{\mu\Phi_{min}^b \ln 2} - \frac{BN_0\Phi_{min}^e(\gamma_n^e - \gamma_n^b)}{(\Phi_{min}^b\Phi_{min}^e(K - K_2) - \tau(\Phi_{min}^b + \Phi_{min}^e))\gamma_n^b\gamma_n^e} \right) \right]^+ \quad (15)$$

$$P_n^e = \left[\frac{BN_0(K_2\Phi_{min}^e + \tau)\Phi_{min}^b}{(\Phi_{min}^b\Phi_{min}^e(K - K_2) - \tau(\Phi_{min}^b + \Phi_{min}^e))\gamma_n^b} - \frac{BN_0(K\Phi_{min}^b - \tau)\Phi_{min}^e}{(\Phi_{min}^b\Phi_{min}^e(K - K_2) - \tau(\Phi_{min}^b + \Phi_{min}^e))\gamma_n^e} \right]^+ \quad (16)$$

where $[x]^+ = \max(x, 0)$ which satisfy constraint (9c). Then the problem (9a) becomes a dual problem which is given by

$$\underset{\mu, \tau}{\text{maximize}} \quad D(\mu, \tau) = \inf_{P_n^b, P_n^e} L(P_n^b, P_n^e, \mu, \tau) \quad (17a)$$

$$\text{subject to} \quad \mu \geq 0. \quad (17b)$$

The dual variables μ and τ can be solved by using the subgradient method in which the valid subgradients are given by

$$\nabla\mu = \sum_{n=1}^N P_n^b + \sum_{n=1}^N P_n^e - P_T \quad (18)$$

$$\nabla\tau = \frac{\sum_{n=1}^N B \log_2(1 + \beta_n^b)}{\Phi_{min}^b} - \frac{\sum_{n=1}^N B \log_2(1 + \beta_n^e)}{\Phi_{min}^e}. \quad (19)$$

In the subgradient method, the dual variables are updated in every iteration starting from specified initial values according to the following expressions:

$$\mu(t+1) = [\mu(t) + \alpha_\mu \nabla\mu]^+ \quad (20)$$

$$\tau(t+1) = \tau(t) + \alpha_\tau \nabla\tau \quad (21)$$

where t is the iteration index, and α_μ and α_τ are the positive step sizes for μ and τ respectively. The initial values and the step sizes affect the convergence towards the optimal solution. Diminishing step size is employed to guarantee near-optimal solution [19]. The subgradient method is summarized in Algorithm 1.

Next we present a low complexity sub-optimal closed form solution.

Algorithm 1 Subgradient Algorithm

```

1: Initialization: set  $t = 0$  and  $\epsilon$ , initialize  $\mu(0)$  and  $\tau(0)$ 
2: while  $|\mu(t-1) - \mu(t)| \geq \epsilon$  and  $|\tau(t-1) - \tau(t)| \geq \epsilon$  do
3:   solve  $P_n^b$  and  $P_n^e$  using (15) and (16) respectively
4:   update  $\mu(t+1)$  using (20)
5:   update  $\tau(t+1)$  using (21)
6:    $t \leftarrow t + 1$ 
7: end while
8: output the optimal solutions  $P_n^{b*}$  and  $P_n^{e*}$ 

```

C. Multicast-based Equal RB Power Allocation (M-ERPA)

As proposed in [14], a closed form power allocation solution can be obtained by assuming the total transmit power allocated to each RB are equal, that is,

$$P_n^b + P_n^e = \frac{P_T}{N} = P_{RB} \quad (22)$$

where P_{RB} is the power allocated to each RB. By using (11) and (12) to solve P_n^e and eliminates the Lagrange variable μ , we obtain

$$P_n^e = BN_0 \left(\frac{(K_2\Phi_{min}^e + \tau)\Phi_{min}^b}{(\Phi_{min}^b\Phi_{min}^e(K - K_2) - \tau(\Phi_{min}^b + \Phi_{min}^e))\gamma_n^b} - \frac{(K\Phi_{min}^b - \tau)\Phi_{min}^e}{(\Phi_{min}^b\Phi_{min}^e(K - K_2) - \tau(\Phi_{min}^b + \Phi_{min}^e))\gamma_n^e} \right). \quad (23)$$

The remaining power in each subcarrier is allocated to the base layer stream and thus, P_n^b can be solve by using (22) and (23) to give

$$P_n^b = P_{RB} - BN_0 \left(\frac{(K_2\Phi_{min}^e + \tau)\Phi_{min}^b}{(\Phi_{min}^b\Phi_{min}^e(K - K_2) - \tau(\Phi_{min}^b + \Phi_{min}^e))\gamma_n^b} - \frac{(K\Phi_{min}^b - \tau)\Phi_{min}^e}{(\Phi_{min}^b\Phi_{min}^e(K - K_2) - \tau(\Phi_{min}^b + \Phi_{min}^e))\gamma_n^e} \right). \quad (24)$$

Although the power allocated to each RB are equal, from (23) and (24), it is noted that the power allocation ratio P_n^b/P_n^e may vary over all RB depending on the values of γ_n^b and γ_n^e . The Lagrange variable τ in (23) and (24) can be solved by substituting these equations into (14) which is given by

$$\tau = \frac{\Phi_{min}^b\Phi_{min}^e(2(K - K_2)\psi_1 + \psi_2 + BN_0\psi_3)}{2\psi_4} \quad (25)$$

where

$$\eta = 2^{(\Phi_{min}^e/\Phi_{min}^b)} \quad (28)$$

$$\psi_1 = \eta P_{RB} (\gamma_n^b)^2 \gamma_n^e (\Phi_{min}^b + \Phi_{min}^e) \quad (29)$$

$$\psi_2 = \sqrt{BN_0} (\gamma_n^b - \gamma_n^e) (K\Phi_{min}^b + K_2\Phi_{min}^e) \times \sqrt{\frac{4\psi_1}{(\Phi_{min}^b + \Phi_{min}^e)} + BN_0 ((\gamma_n^b - \gamma_n^e)^2 + 4\eta\gamma_n^b\gamma_n^e)} \quad (30)$$

$$\psi_3 = (K\Phi_{min}^b - K_2\Phi_{min}^e) (\gamma_n^b - \gamma_n^e)^2 + 2\eta\gamma_n^b\gamma_n^e (\Phi_{min}^b + \Phi_{min}^e) (K - K_2) \quad (31)$$

$$P_n^b = P_{RB} + \frac{BN_0 ((\gamma_n^b \Phi_{min}^e + \gamma_n^e \Phi_{min}^b) (2(K - K_2) \psi_1 + \psi_2 + BN_0 \psi_3) + 2(K_2 \gamma_n^e - K \gamma_n^b) \psi_4)}{\gamma_n^b \gamma_n^e ((\Phi_{min}^b + \Phi_{min}^e) (2(K - K_2) \psi_1 + \psi_2 + BN_0 \psi_3) + 2(K_2 - K) \psi_4)} \quad (26)$$

$$P_n^e = - \frac{BN_0 ((\gamma_n^b \Phi_{min}^e + \gamma_n^e \Phi_{min}^b) (2(K - K_2) \psi_1 + \psi_2 + BN_0 \psi_3) + 2(K_2 \gamma_n^e - K \gamma_n^b) \psi_4)}{\gamma_n^b \gamma_n^e ((\Phi_{min}^b + \Phi_{min}^e) (2(K - K_2) \psi_1 + \psi_2 + BN_0 \psi_3) + 2(K_2 - K) \psi_4)} \quad (27)$$

$$\psi_4 = \psi_1 (\Phi_{min}^b + \Phi_{min}^e) + BN_0 (\Phi_{min}^b \Phi_{min}^e (\gamma_n^b - \gamma_n^e)^2 + \gamma_n^b \gamma_n^e (\Phi_{min}^b + \Phi_{min}^e)^2). \quad (32)$$

Finally, the closed form sub-optimal power for the base and enhancement layer streams can be solve by substituting (25) into (24) and (23) respectively to give the expressions (26) and (27).

IV. SIMULATION RESULTS

We consider a downlink NOMA network consisting of a BS located in the centre of the cell and five mobile users uniformly distributed within a circular cell radius of 500 m. The number of users in subgroup $\mathcal{G}_2$ is set as three and the remaining two users with the weakest channel gain is in subgroup $\mathcal{G}_1$ to ensure that more than 50% of the users achieve excellent quality of service. The minimum target rate specified for base and enhancement layer streams are 1 Mbps and 1.5 Mbps respectively. This means that the users in the strong group will have a combined minimum rate of 2.5 Mbps. The wireless channel impairment due to path loss, shadowing effect, noise and frequency selective fading are taken into account and the associated parameters are depicted in Table I. The performance of the optimal power allocation, which is solved using numerical tool, is compared to the proposed subgradient method and M-ERPA as well as other existing NOMA power allocation schemes including Fixed Power Allocation (FPA) and Fractional Transmit Power Allocation (FTPA) [5][12].

Table I
SIMULATION PARAMETERS

Parameters	Values/Model
No. of RB, N	25
Total Bandwidth, B_T	5 MHz
Cell radius	500 m
Carrier frequency, f_c	2 GHz
Path loss, PL	$PL(d_0) + 10v \log_{10} \left(\frac{d}{d_0} \right)$
Reference distance, d_0	1 m
Path loss exponent, v	3
Log normal shadowing	$\sigma=8$ dB
Noise power spectral density, N_0	-174 dBm/Hz
Frequency Selective Fading	ITU Pedestrian B
Antenna Configuration	SISO

The optimal solution is established as the upper bound performance for the proposed and the existing power allocation schemes. Fig. 3 illustrates the sum rate performance versus the total power constraints which vary from 34 dBm to 46 dBm. From this figure, the subgradient method performs very closely to the optimal numerical solution, and is better

than the proposed closed form scheme at the expense of higher complexity. Furthermore, the proposed closed form solution outperforms the existing FPA and FTPA schemes which have comparatively similar complexity. The figure also shows that the performance of NOMA utilizing any of the power allocation schemes considered in this paper is superior compared to the optimal OFDMA.

Figure 3. Performance in terms of sum rate versus total transmission power

Figure 4. User transmission rate performance versus total transmission power

In Fig. 4, the transmission rate performance of individual user in each subgroup versus the total power constraints is presented. For FPA and FTPA, the users in subgroup $\mathcal{G}_1$ suffer

from a lower rate at the cost of higher data rate achieved by the users in subgroup $\mathcal{G}_2$ which results in significantly lower sum rate as illustrated in Fig. 3. Whereas, in subgradient method and the proposed M-ERPA, the users in subgroup $\mathcal{G}_1$ achieve considerably higher transmission rates and users in subgroup $\mathcal{G}_2$ only experience considerably small degradation as compared to FPA and FTPA. This indicates that the proposed schemes maintain a good degree of fairness whilst achieving higher sum rate performance.

V. CONCLUSIONS

By considering multi-rate multicast technique achieved by user grouping and content splitting via layered coding for video, we have investigated the power allocation for multicarrier NOMA-based multicast system. Near-optimal and low-complexity sub-optimal solutions are proposed for the allocation of power to both base and enhancement layer streams over each RB. The comparisons between the optimal and the proposed methods as well as the existing methods, FPA and FTPA, are presented. Simulation results show that both subgradient method and M-ERPA achieve comparable sum rate performance as the optimal solution while outperforming the FPA and FTPA techniques. Although M-ERPA is outperformed by the subgradient method, it offers much lower complexity and therefore M-ERPA is more suitable for practical implementation. Furthermore, it is also observed that the proposed methods, subgradient method and M-ERPA, offer good fairness to the users with poor channel conditions while achieving higher sum rates. Although this work only considers a single multicast group, the work can be extended to multiple multicast groups by allocating these groups into different subbands.

REFERENCES

- [1] ITU and UNESCO. (2016, Sep.) The state of broadband 2016: Broadband catalyzing sustainable development. [Online]. Available: <http://broadbandcommission.org/Documents/reports/bb-annualreport2016.pdf>
- [2] Cisco. (2017, Feb.) Cisco visual networking index: Global mobile data traffic forecast update, 2016-2021. [Online]. Available: <http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.pdf>
- [3] P. K. Agyapong, M. Iwamura, D. Staehle, W. Kiess, and A. Benjebbour, "Design considerations for a 5G network architecture," *IEEE Communications Magazine*, vol. 52, no. 11, pp. 65–75, 2014.
- [4] Z. Ding, Y. Liu, J. Choi, Q. Sun, M. Elkashan, C. I. and H. Poor, "Application of non-orthogonal multiple access in LTE and 5G networks," *IEEE Communications Magazine*, vol. 55, no. 2, pp. 185–191, 2017.
- [5] A. Benjebbour, A. Li, Y. Kishiyama, A. Harada, and T. Nakamura, "System-level performance of downlink NOMA for future LTE enhancements," in *Proc. IEEE Globecom Workshops 2013 (GC Wkshps 2013)*, pp. 66–70, Dec. 2013.
- [6] S. M. Riazul Islam, N. Avazov, O. A. Dobre, and K. Kwak, "Power-domain non-orthogonal multiple access (NOMA) in 5G systems: Potentials and challenges," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, pp. 721–742, 2017.
- [7] R. O. Afolabi, A. Dadlani, and K. Kim, "Multicast scheduling and resource allocation algorithms for OFDMA-based systems: A survey," *IEEE Communications Surveys & Tutorials*, vol. 15, no. 1, pp. 240–254, 2013.
- [8] J. Choi, "Minimum power multicast beamforming with superposition coding for multiresolution broadcast and application to NOMA systems," *IEEE Transactions on Communications*, vol. 63, no. 3, pp. 791–800, 2015.
- [9] J. Wolf, A. Wyner, and J. Ziv, "Source coding for multiple descriptions," *The Bell System Technical Journal*, vol. 59, no. 8, pp. 1417–1426, 1980.
- [10] W. Li, "Overview of fine granulatly scalability in MPEG-4 video standard," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 11, no. 3, pp. 301–317, 2001.
- [11] H. Schwarz, D. Marpe, and T. Wiegand, "Overview of the scalable video coding extension of the H.264/AVC standard," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 17, no. 9, pp. 1103–1120, 2007.
- [12] N. Otao, Y. Kishiyama, and K. Higuchi, "Performance of non-orthogonal access with SIC in cellular downlink using proportional fair-based resource allocation," in *Proc. IEEE ISWCS*, pp. 476–480, Aug. 2012.
- [13] Z. Q. Al-Abbasi and D. K. C. So, "Power allocation for sum rate maximization in non-orthogonal multiple access system," in *Proc. IEEE PIMRC 2015*, pp. 1649 – 1653, Sept. 2015.
- [14] Z. Q. Al-Abbasi and D. K. C. So, "Resource allocation in non-orthogonal and hybrid multiple access system with proportional rate constraint," *IEEE Transactions on Wireless Communications*, accepted, July 2017.
- [15] Z. Ding, Z. Yang, P. Fan, and H. Poor, "On the performance of non-orthogonal multiple access in 5G systems with randomly deployed users," *IEEE Signal Processing Letters*, vol. 21, no. 12, pp. 1501–1505, 2014.
- [16] L. Lv, J. Chen, and Q. Ni, "Cooperative non-orthogonal multiple access in cognitive radio," *IEEE Communications Letters*, vol. 20, no. 10, pp. 2059–2062, 2016.
- [17] L. Lv, J. Chen, Q. Ni, and Z. Ding, "Design of cooperative non-orthogonal multicast cognitive multiple access for 5G systems: User scheduling and performance analysis," *IEEE Transactions on Communications*, vol. 65, no. 6, pp. 2641–2656, 2017.
- [18] S. Boyd and L. Vandenberghe, *Convex Optimization*. Cambridge University Press, 2004.
- [19] D. Palomar and M. Chiang, "A tutorial on decomposition methods for network utility maximization," *IEEE Journal on Selected Areas in Communications*, vol. 24, no. 8, pp. 1439–1451, 2006.