Admission Control in 5G Networks for the Coexistence of eMBB-URLLC Users

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Abstract—In this paper, we consider the problem of admission control in 5G networks where enhanced mobile broadband (eMBB) users and ultra-reliable low-latency communication (URLLC) users are coexisting. URLLC users require low latency and high reliability while eMBB users require high data rates. Thus, it is essential to control the admission of eMBB users while giving priority to all URLLC users in a network where both types of users are coexisting. Our aim is to maximize the number of admitted eMBB users to the system with a guaranteed data rate while allocating resources to all URLLC users. We formulated this as an ℓ_0 minimization problem. Since it is an NP-hard problem we have used approximation methods and sequential convex programming to obtain a suboptimal solution. Numerically we have shown that the proposed algorithm achieves near-optimal performance. Our algorithm is able to maximize the number of admitted eMBB users with an optimal allocation of resources while giving priority to all URLLC users.

Index Terms—eMBB and URLLC users, MISO, finite blocklength regime, effective bandwidth, bandwidth allocation, power allocation, sequential convex programming.

I. INTRODUCTION

Fifth generation (5G) new radio (NR) supports three main use cases. They are enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (URLLC) and massive machine-type communications (mMTC). According to 3GPP, quality of service (QoS) requirements of URLLC is ultra-high reliability and low transmission latency, whereas eMBB requires high data rates [1]. The coexistence of eMBB and URLLC users in the same resource is a difficult issue since simultaneously achieving high data rates for eMBB users and the ultra reliability and low latency for URLLC users becomes a challenging scheduling task due to the trade-off between latency, reliability and achieving high data rates.

Admission control in wireless networks can be interpreted as finding the maximum amount of traffic or maximum number of users that can be admitted simultaneously to the system while efficiently using the available resources and satisfying QoS requirements. The admission control problem is formulated as an ℓ_0 minimization problem in [2] for multi-cell downlink multiple-input single-output (MISO) system. Authors in [3] have proposed two algorithms to solve the optimization problem of admission control using semi-definite relaxation method and the second-order cone programming

method. Multi-user admission control and beamformer optimization for the MISO heterogeneous networks is considered in [3]. Authors in [4] are suggesting suboptimal greedy search algorithm for solving the admission control problem and finding optimal power and bandwidth allocations.

Effective bandwidth is the minimum amount of the bandwidth required to satisfy QoS requirements [5]. If the maximum achievable rate of the URLLC user is greater than or equal to the effective bandwidth, which was derived using the reliability and latency values, we can say that reliability and latency requirement of the URLLC user is guaranteed [5]–[8]. Most of the scheduling algorithms for the coexistence of eMBB and URLLC in literature suggest puncturing eMBB users, in order to give priority to URLLC users and satisfy their reliability and latency requirements [1], [9]–[11].

URLLC users are time and mission critical, therefore they need to be given priority when they have something to transmit. However, eMBB users are best effort users, they need higher data rate than the other requirements. Thus, to accommodate it we need to control the admissions of eMBB users and facilitate scheduling all the URLLC users. Therefore, it is essential to know the possible number of eMBB users that can be supported by the system while meeting the reliability and latency requirements of URLLC users. However, no research has been found which considers the admission control problem in the wireless network where eMBB users and URLLC users are coexisting.

In this paper, we propose an algorithm to solve the admission control problem in 5G networks where eMBB and URLLC users are coexisting [12] [1], [13] [2]. The objective of the problem is to maximize the number of admitted eMBB users under four constraints: 1) signal-to-interference-plus-noise ratio constraint for eMBB users which is derived through Shannon's rate, 2) signal-to-noise ratio constraints for URLLC users in order to satisfy high reliability and low latency requirements of URLLC users which is derived through the approximation of Shannon's rate in short blocklength regime and simplified using the notion of effective bandwidth to obtain a lower bound, 3) transmit power constraint and 4) total bandwidth constraint.

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[1] This paper is based on the research findings of the first author's master's thesis [12]

[2] A pre-conference version of this papaer is published in [13]

The proposed algorithm finds the maximum number of eMBB users who have sufficient data rates that can be admitted to the system while allocating power, bandwidth and beamforming directions to all URLLC users whose latency and reliability requirements are always guaranteed. The algorithm is derived using sequential convex programming. Numerically, we show that the proposed algorithm achieves near-optimal performance.

The rest of the paper is organized as follows. The system model and the problem formulation are presented in Section II. The proposed admission control algorithm is presented in Section III. The numerical results are presented in Section IV and Section V concludes our paper.

II. System Model and Problem Formulation

We consider the downlink of a single-cell MISO system where eMBB users and URLLC users are coexisting as shown in Fig.1. We assume that the base station have T transmit antennas. The set of all the users in the network is denoted by $\mathcal{U}$. The set of all eMBB users denoted by $\mathcal{U}_e \subset \mathcal{U}$ and they are labeled with the integer values $k = 1, \ldots, K$. We use the notation $\mathcal{U}_u \subset \mathcal{U}$ to denote the set of all URLLC users and they are labeled with the integer values $j = 1, \ldots, J$. We assume that all users have only one receive antenna.
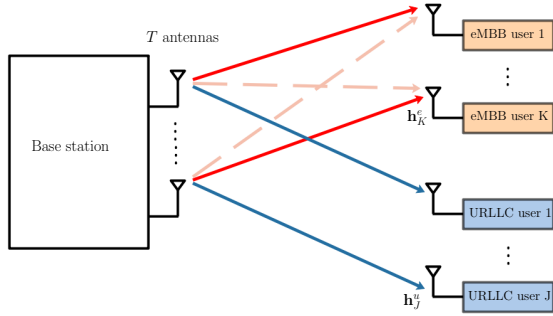

Fig. 1. Illustration of the system model.

We consider eMBB and URLLC users coexist using orthogonal spectrum sharing approach [11]. Let the total bandwidth of the system be B_{total}, total bandwidth for eMBB users be b^e and that of URLLC users be b^u. Note that there is no interference between eMBB users and URLLC users, since they are getting a separate portion of bandwidth. Furthermore, we consider orthogonal frequency division multiple access (OFDMA) for URLLC users. Thus, the URLLC users are scheduled in orthogonal resources, hence there is no interference between URLLC users.

We assume that bandwidth allocation for all eMBB users and for each URLLC user is less than or equal to the total bandwidth of the system B_{total}, i.e.,

$$b^e + \sum_{j=1}^{J} b_j^u \leq B_{total}, \quad (1)$$

where b_j^u is the bandwidth allocated to jth URLLC user.

The signal vector transmitted by the base station is given by $\mathbf{x} = \sum_{k \in \mathcal{U}} \mathbf{m}_k d_k$, where d_k is the normalized data symbol of

kth user, and we assume that the data streams are independent. The beamforming vector of kth user, $\mathbf{m}_k \in \mathbb{C}^T$ can be written as $\mathbf{m}_k = \sqrt{p_k} \mathbf{u}_k$, where $\mathbf{u}_k \in \mathbb{C}^T$ is the normalized beamformer and p_k is the power of kth user.

Received signal vector of kth eMBB user is given by

$$y_k^e = (\mathbf{h}_k^e)^{\mathrm{H}} \mathbf{m}_k^e d_k^e + \sum_{i=1, i \neq k}^{K} (\mathbf{h}_k^e)^{\mathrm{H}} \mathbf{m}_i^e d_i^e + w_k^e, \quad (2)$$

where $\mathbf{h}_k^e \in \mathbb{C}^T$ is the channel vector from base station to eMBB user k, $\mathbf{m}_k^e \in \mathbb{C}^T$ is the beamforming vector of kth eMBB user and $w_k^e \sim CN(0, \sigma_e^2)$ is the additive white Gaussian noise (AWGN) at eMBB user k. We consider the noise variance as $\sigma_e^2 = N_0 b^e$, where N_0 is single-sided noise spectral density.

Received signal of jth URLLC user can be written as

$$y_j^u = (\mathbf{h}_j^u)^{\mathrm{H}} \mathbf{m}_j^u d_j^u + w_j^u, \quad (3)$$

where $\mathbf{h}_j^u \in \mathbb{C}^T$ is the channel vector from base station to URLLC user j, $\mathbf{m}_j^u \in \mathbb{C}^T$ is the beamforming vector of jth URLLC user and $w_j^u \sim CN(0, \sigma_{j,u}^2)$ is the additive white Gaussian noise (AWGN) at URLLC user j. We consider the noise variance as $\sigma_{j,u}^2 = N_0 b_j^u$.

The received SINR of kth eMBB user can be expressed as

$$\gamma_k^e = \frac{|(\mathbf{h}_k^e)^{\mathrm{H}} \mathbf{m}_k^e|^2}{\sum_{i=1, i \neq k}^{K} |(\mathbf{h}_k^e)^{\mathrm{H}} \mathbf{m}_i^e|^2 + N_0 b^e}. \quad (4)$$

The received SINR of jth URLLC user can be expressed as

$$\gamma_j^u = \frac{|(\mathbf{h}_j^u)^{\mathrm{H}} \mathbf{m}_j^u|^2}{N_0 b_j^u}. \quad (5)$$

The maximum achievable rate for kth eMBB user can be written as

$$R_k^e = b^e \log_2(1 + \gamma_k^e). \quad (6)$$

We assume that the target rate for an eMBB user is R_{target}. Thus, the target SINR for kth eMBB user, $\gamma_k^{e,tar}$ can be expressed as

$$\gamma_k^{e,tar} = 2^{\frac{R_{target}}{b^e}} - 1. \quad (7)$$

The target rate for eMBB users can be achieved if its SINR, which is mentioned in (4), is greater than the SINR threshold, $\gamma_k^{e,tar}$, i.e.,

$$\gamma_k^e \geq \gamma_k^{e,tar}. \quad (8)$$

The overall packet loss probability requirement of an URLLC user is the probability of the complement of overall reliability requirement. The overall packet loss probability, ϵ can be expressed as $\epsilon = \epsilon_c + \epsilon_q$, where ϵ_c is the transmission-error probability and ϵ_q is the queuing-delay violation probability.

Furthermore, we assume that downlink transmission only requires one frame and duration of one frame is T_f. Moreover, the latency of the backhaul is equal to the duration of one frame, T_f. Thus, we can obtain end to end queuing delay by $D_q = D_{max} - 2T_f$, where D_{max} is the maximum packet delay threshold.

If channel state information (CSI) is known at the transmitter and receiver, in quasi-static, interference-free, flat fading channel, the achievable rate of jth user can be approximated by [8],

$$R_j^u = \frac{\tau b_j^u}{\ln 2}[\ln(1 + \gamma_j^u) - \sqrt{\frac{V_j^u}{\tau b_j^u}}Q^{-1}(\epsilon_c)] \ bits/frame, \quad (9)$$

where τ is the duration for data transmission in one frame, Q^{-1} is the inverse Q function and V_j^u is channel dispersion of URLLC user j, which is given by

$$V_j^u = 1 - \frac{1}{(1 + \gamma_j^u)^2}. \quad (10)$$

The channel coherence time is greater than the end to end delay since URLLC has an end to end delay less than 1 ms. This means URLLC users have a quasi-static channel and the rate of URLLC users, which is mentioned in (9), can consider as a constant for a given resource allocation policy. The queuing delay requirements (D_q and ϵ_q) can be satisfied when this constant achievable rate is greater than or equal to the effective bandwidth [5]–[8]. The effective bandwidth for a Poisson process with arrival packet rate λ, can be expressed as [6],

$$E^B = \frac{\mu T_f \ln\frac{1}{\epsilon_q}}{D_q \ln\left(\frac{T_f \ln\frac{1}{\epsilon_q}}{\lambda D_q} + 1\right)} \ bits/frame, \quad (11)$$

where μ is the number of bits contained in each packet. We can obtain a lower bound for the SNR required to satisfy queuing delay requirements by substituting $R_j^u = E^B$ and $V_j^u \approx 1$. Thus, the threshold for SNR of URLLC user j is given by

$$\gamma_j^{u,tar} = \exp\left[\frac{E^B \ln 2}{\tau b_j^u} + \sqrt{\frac{1}{\tau b_j^u}}Q^{-1}(\epsilon_c)\right] - 1. \quad (12)$$

Latency and reliability requirements of jth URLLC user is satisfied if SNR of jth URLLC user, which is mentioned in (5), is greater than the SINR threshold $\gamma_j^{u,tar}$, i.e.,

$$\gamma_j^u \geq \gamma_j^{u,tar}. \quad (13)$$

We assume that the total power allocated for both eMBB and URLLC users is less than or equal to maximum transmit power at the base station P_{total}, i.e.,

$$\sum_{k=1}^{K} \| \mathbf{m}_k^e \|_2^2 + \sum_{j=1}^{J} \| \mathbf{m}_j^u \|_2^2 \leq P_{total}. \quad (14)$$

It is needed to prioritize URLLC users due to their low latency and high reliability requirements. However, eMBB users require high data rates. We have to control the admission of eMBB users in order for their coexistence. Hence, our goal is to maximize the number of admitted eMBB users such that all the constraints related to eMBB and URLLC users are satisfied. Thus, we need to maximize the cardinality of $\mathcal{U}_e$. To formulate this problem as a mathematical optimization problem we define the non negative auxiliary variable s_k and relax the SINR constraint for kth eMBB user as follows:

$$\gamma_k^e \geq \gamma_k^{e,tar} - s_k. \quad (15)$$

In (15), we can obtain (8) when $s_k = 0$. That means when $s_k = 0$ the SINR constraint of kth eMBB user is satisfied. Therefore, in order to maximize the number of admitted eMBB users who achieve the target rate, we have to minimize the number of users that require a strictly positive value of auxiliary variable s_k. In other words we have to make maximum number of s_k's to be zeros. Hence the problem of admission control for eMBB in the coexistence of URLLC and eMBB users can be expressed as

$$\begin{aligned} \text{minimize} \quad & \| \mathbf{s} \|_0 \\ \text{subject to} \quad & \gamma_k^e \geq \gamma_k^{e,tar} - s_k, \forall \ k \in \mathcal{U}_e & (16a) \\ & \gamma_j^u \geq \gamma_j^{u,tar}, \forall \ j \in \mathcal{U}_u & (16b) \\ & b^e + \sum_{j=1}^{J} b_j^u \leq B_{total} & (16c) \\ & b^e \geq 0 & (16d) \\ & b_j^u \geq 0, \forall \ j \in \mathcal{U}_u & (16e) \\ & \sum_{k=1}^{K} \| \mathbf{m}_k^e \|_2^2 + \sum_{j=1}^{J} \| \mathbf{m}_j^u \|_2^2 \leq P_{total} & \\ & & (16f) \\ & s_k \geq 0, \forall \ k \in \mathcal{U}_e, & (16g) \end{aligned}$$

where $\mathbf{s} = [s_1, \ldots, s_k]^T$ and optimization variables are $\{s_k, \mathbf{m}_k^e\} \ \forall \ k \in \mathcal{U}_e$, b^e and $\{\mathbf{m}_j^u, b_j^u\} \ \forall \ j \in \mathcal{U}_u$.

III. ALGORITHM DERIVATION

Problem (16) has an ℓ_0 objective function and it is known as an NP-hard problem. Thus, it is exponentially complex to find an optimal solution to this problem. We provide a suboptimal algorithm that can find a suboptimal solution to the problem. The proposed algorithm is based on ℓ_0 approximation method and sequential convex programming.

We approximate the objective function with a concave function $\sum_{k=1}^{K} \log(s_k + \delta)$ where δ is small positive constant and $s_k \geq 0, \ \forall \ k \in \mathcal{U}_e$ [14]. We denote the interference plus noise experienced by kth eMBB user, by the variable β_k as $\beta_k = \sum_{i=1, i \neq k}^{K} |(\mathbf{h}_k^e)^H \mathbf{m}_i^e|^2 + N_0 b^e$. Hence, the original optimization problem (16) can be approximated as the following optimization problem:

minimize $\quad \sum_{k=1}^{K} \log(s_k + \delta)$

subject to $\quad 2^{\frac{R_{target}}{b^e}} - 1 - s_k - \frac{|(\mathbf{h}_k^e)^{\mathrm{H}}\mathbf{m}_k^e|^2}{\beta_k} \leq 0, \forall~ k \in \mathcal{U}_e$ (17a)

$$\sum_{i=1,i\neq k}^{K} |(\mathbf{h}_k^e)^{\mathrm{H}}\mathbf{m}_i^e|^2 + N_0 b^e \leq \beta_k, \forall~ k \in \mathcal{U}_e$$ (17b)

$$\exp\left[\frac{E^B \ln 2}{\tau b_j^u} + \sqrt{\frac{1}{\tau b_j^u}}Q^{-1}(\epsilon_c)\right] - 1$$
$$- \frac{|(\mathbf{h}_j^u)^{\mathrm{H}}\mathbf{m}_j^u|^2}{N_0 b_j^u} \leq 0, \forall~ j \in \mathcal{U}_u \quad (17c)$$

constraints $(16c), (16d), (16e), (16f), (16g),$ (17d)

where optimization variables are $\{s_k, \mathbf{m}_k^e\}~\forall~k \in \mathcal{U}_e$, b^e and $\{\mathbf{m}_j^u, b_j^u\}~\forall~j \in \mathcal{U}_u$.

Problem (17) is still non convex, because still it has a concave objective function and non convex constraint functions, i.e., the constraints (17a) and (17c) are non convex. Therefore, to solve the the problem (17), we apply sequential convex programming [15].

We denote the objective function of the problem (17) by $f(s) = \sum_{k=1}^{K} \log(s_k + \delta)$. Since $f(s)$ is a concave function [16, Ch. 3], we consider its first order approximation, and approximation of the objective function can be denoted by [15],

$$\hat{f}(\mathbf{s}) = f(\hat{s}) + \sum_{k=1}^{K}(s_k - \hat{s}_k)/(\hat{s}_k + \delta), \quad (18)$$

and it is evaluated at the point $\hat{\mathbf{s}} = [\hat{s}_1, ..., \hat{s}_K]$.

The constraint (17a) is in the form of 'difference of convex' function. We apply convex - concave procedure to make the constraint (17a) convex [15]. We define $g_k(\mathbf{m}_k^e, \beta_k)$ as $g_k(\mathbf{m}_k^e, \beta_k) = |(\mathbf{h}_k^e)^{\mathrm{H}}\mathbf{m}_k^e|^2/\beta_k$. First order approximation of $g_k(\mathbf{m}_k^e, \beta_k)$ is as follows:

$$\hat{g}_k(\mathbf{m}_k^e, \beta_k) = g_k(\hat{\mathbf{m}}_k^e, \hat{\beta}_k)$$
$$+ \nabla g_k(\hat{\mathbf{m}}_k^e, \hat{\beta}_k)^{\mathrm{T}}((\mathbf{m}_k^e, \beta_k) - (\hat{\mathbf{m}}_k^e, \hat{\beta}_k)), \quad (19)$$

where $\nabla g_k(\hat{\mathbf{m}}_k^e, \hat{\beta}_k)$ is the gradient of $g_k(\mathbf{m}_k^e, \beta_k)$ which is evaluated at the point $(\hat{\mathbf{m}}_k^e, \hat{\beta}_k)$. $\nabla g_k(\hat{\mathbf{m}}_k^e, \hat{\beta}_k)$ is given by

$$\nabla g_k(\hat{\mathbf{m}}_k^e, \hat{\beta}_k) = \left(\frac{2\mathbf{h}_k^e(\mathbf{h}_k^e)^{\mathrm{H}}\hat{\mathbf{m}}_k^e}{\hat{\beta}_k}, \frac{-(\hat{\mathbf{m}}_k^e)^{\mathrm{H}}\mathbf{h}_k^e(\mathbf{h}_k^e)^{\mathrm{H}}\hat{\mathbf{m}}_k^e}{\hat{\beta}_k^2}\right).$$
(20)

The constraint (17c) is also in the form of 'difference of convex' function. We apply convex - concave procedure to make the constraint (17c) convex [15]. We define $z_j(\mathbf{m}_j^u, b_j^u)$ as, $z_j(\mathbf{m}_j^u, b_j^u) = |(\mathbf{h}_j^u)^{\mathrm{H}}\mathbf{m}_j^u|^2/N_0 b_j^u$. The first order approximation of $z_j(\mathbf{m}_j^u, b_j^u)$ is as follows:

$$\hat{z}_j(\mathbf{m}_j^u, b_j^u) = z_j(\hat{\mathbf{m}}_j^u, \hat{b}_j^u)$$
$$+ \nabla z_j(\hat{\mathbf{m}}_j^u, \hat{b}_j^u)^{\mathrm{T}}((\mathbf{m}_j^u, b_j^u) - (\hat{\mathbf{m}}_j^u, \hat{b}_j^u)), \quad (21)$$

where $\nabla z_j(\hat{\mathbf{m}}_j^u, \hat{b}_j^u)$ is the gradient of $z_j(\mathbf{m}_j^u, b_j^u)$ which is evaluated at the point $(\hat{\mathbf{m}}_j^u, \hat{b}_j^u)$. $\nabla z_j(\hat{\mathbf{m}}_j^u, \hat{b}_j^u)$ is given by

$$\nabla z_j(\hat{\mathbf{m}}_j^u, \hat{b}_j^u) = \left(\frac{2\mathbf{h}_j^u(\mathbf{h}_j^u)^{\mathrm{H}}\hat{\mathbf{m}}_j^u}{N_0 \hat{b}_j^u}, \frac{-(\hat{\mathbf{m}}_j^u)^{\mathrm{H}}\mathbf{h}_j^u(\mathbf{h}_j^u)^{\mathrm{H}}\hat{\mathbf{m}}_j^u}{N_0(\hat{b}_j^u)^2}\right).$$
(22)

Now by using expressions (18), (19) and (21), we approximate the problem (17) as the following convex optimization problem:

minimize $\quad \sum_{k=1}^{K} s_k/(\hat{s}_k + \delta)$

subject to $\quad 2^{\frac{R_{target}}{b^e}} - 1 - s_k - \hat{g}_k(\mathbf{m}_k^e, \beta_k) \leq 0, \forall~ k \in \mathcal{U}_e$ (23a)

$$\sum_{i=1,i\neq k}^{K} |(\mathbf{h}_k^e)^{\mathrm{H}}\mathbf{m}_i^e|^2 + N_0 b^e \leq \beta_k, \forall~ k \in \mathcal{U}_e$$ (23b)

$$\exp\left[\frac{E^B \ln 2}{\tau b_j^u} + \sqrt{\frac{1}{\tau b_j^u}}Q^{-1}(\epsilon_c)\right] - 1$$
$$- \hat{z}_j(\mathbf{m}_j^u, b_j^u) \leq 0, \forall~ j \in \mathcal{U}_u \quad (23c)$$

constraints $(16c), (16d), (16e), (16f), (16g),$ (23d)

where the optimization variables are $\{s_k, \mathbf{m}_k^e\}~\forall~k \in \mathcal{U}_e$, b^e and $\{\mathbf{m}_j^u, b_j^u\}$ for $\forall~j \in \mathcal{U}_u$. We have dropped the constant terms $f(\hat{s})$ and $\hat{s}_k/\hat{s}_k + \delta$ from the objective function of problem (23), since they are not affecting the solution.

The proposed algorithm for solving problem (23) is summarized in *Algorithm 1*.

Algorithm 1 Algorithm for solving problem (23)

1: **initialization:** $\{s_k^0, (\mathbf{m}_k^e)^0, \beta_k^0\}~\forall~k \in \mathcal{U}_e$, b^e and $\{(\mathbf{m}_j^u)^0, (b_j^u)^0\}~\forall~j \in \mathcal{U}_u$, iteration index $p = 0$.
   repeat
2: Set $\hat{\mathbf{m}}_k^e = (\mathbf{m}_k^e)^p$, $\hat{\beta}_k = \beta_k^p~\forall~k \in \mathcal{U}_e$ and $\hat{\mathbf{m}}_j^u = (\mathbf{m}_j^u)^p$, $\hat{b}_j^u = (b_j^u)^p~\forall~j \in \mathcal{U}_u$. Form $\hat{g}_k(\mathbf{m}_k^e, \beta_k)~\forall k$ using (19) and $\hat{z}_j(\mathbf{m}_j^u, b_j^u)~\forall j$ using (21).
3: Solve problem (23). Denote the solution $\{s_k^\star, (\mathbf{m}_k^e)^\star, \beta_k^\star\}~\forall~k \in \mathcal{U}_e$ and $\{(\mathbf{m}_j^u)^\star, (b_j^u)^\star\}~\forall~j \in \mathcal{U}_u$. Set $p = p + 1$.
4: Update $\{s_k^{p+1} = s_k^\star, (\mathbf{m}_k^e)^{p+1} = (\mathbf{m}_k^e)^\star, \beta_k^{p+1} = \beta_k^\star\}~\forall~k \in \mathcal{U}_e$ and $\{(\mathbf{m}_j^u)^{p+1} = (\mathbf{m}_j^u)^\star, (b_j^u)^{p+1} = (b_j^u)^\star\}~\forall~j \in \mathcal{U}_u$.
   until stopping criterion is satisfied

The algorithm is iterated until the difference between the objective values of problem (23) in consecutive iterations is less than a predefined threshold.

IV. NUMERICAL RESULTS

We simulate the proposed algorithm in order to prove the correctness and effectiveness of our algorithm. In our simulations, the downlink of a single-cell MISO system is considered. We assume that the base station is equipped with four transmit antennas. There are eight eMBB users and eight

URLLC users in the system. To model the channel gains, we have used the exponential path loss model which is given by $\mathbf{h}_k = (r_k/r_0)^{-\alpha}\mathbf{c}_k$, where $\mathbf{h}_k \in \mathbb{C}^T$ is the channel vector from base station to kth user, r_k is the distance from base station to kth user, r_0 is the far-field reference distance, α is the path loss exponent and $\mathbf{c}_k$ is small scale fading which is arbitrary chosen from circularly symmetric complex Gaussian vector distribution with mean zero and identity covariance matrix. We assume that both eMBB and URLLC users are distributed uniformly around the base station within the distance 10 m and 100 m. We consider the bandwidth allocation between eMBB users and URLLC users as total bandwidth for eMBB users, $b^e = B_{total} \times (1/2)$ and the total bandwidth of URLLC users, $b^u = B_{total} \times (1/2)$. Furthermore, the simulation parameters mentioned in Table I are assumed.

Fig. 2. Objective value versus iterations and number of admitted users versus iterations.

TABLE I
SIMULATION PARAMETERS

Far field distance r_0	1 m
Path loss exponent α	2
Overall packet loss probability requirement ϵ	1×10^{-5}
Transmission error probability $\epsilon_c = \epsilon/2$	5×10^{-6}
Queueing-delay violation probability $\epsilon_q = \epsilon/2$	5×10^{-6}
E2E delay requirement D_{max}	1 ms
Maximum queueing delay D_q	0.8 ms
Duration of each frame T_f	0.1 ms
Duration of data transmission in one frame τ	0.05 ms
Packet size μ	20 bytes
Maximum transmit power P_{total}	33 dBm
Arrival packet rate λ	0.2 packets/frame
Single-sided noise spectral density N_0	-83.98 dBm/Hz [11]
Total bandwidth of the system B_{total}	200 MHz
Target rate for an eMBB user R_{target}	200 Mbps

We simulate an arbitrarily chosen single channel and topology realization. The objective value $f(s) = \sum_{k=1}^{K} \log(s_k + \delta)$ is calculated for every iteration until convergence. Furthermore, we count the admitted number of eMBB users at each iteration. Then we draw the objective value versus iteration and number of admitted users versus iteration in the same graph in order to check the convergence of the algorithm.

Fig. 2 shows the behaviour of the convergence of the *Algorithm 1*. According to Fig. 2, the objective value is minimized and converged after eight iterations. At the convergence we are able to get the optimal solution of the algorithm as four eMBB users can be admitted to the system. Therefore, we can observe that, our algorithm is obtaining the optimal solution in few iterations.

Next, we evaluate how the admitted number of eMBB users behave with the target rate for eMBB user and the total bandwidth of the system. The algorithm has been run over 100 channel and topology realizations. We simulate it for different ratios of eMBB and URLLC bandwidth allocation from the total bandwidth of the system. Table II shows the two different cases that we have simulated. As a benchmark, we consider an exhaustive search algorithm. (We name *Algorithm 1* as Algo 1).

The variation of the admitted number of users with the target rate of eMBB users for different values of total bandwidth
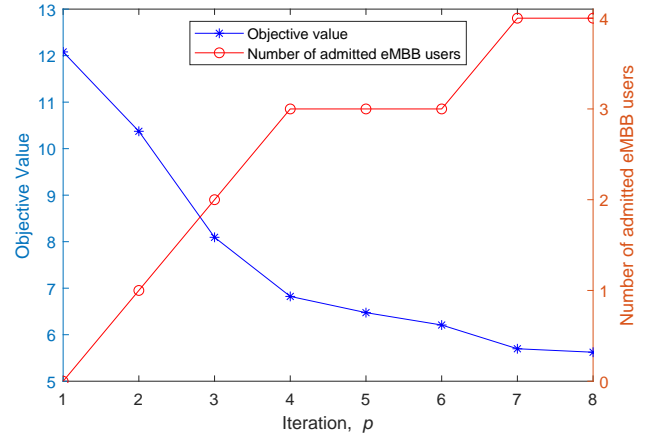
TABLE II
EMBB AND URLLC BANDWIDTH ALLOCATION

Case	Bandwidth portion for eMBB (b^e)	Bandwidth portion for URLLC (b^u)
1	$B_{total} \times (3/4)$	$B_{total} \times (1/4)$
2	$B_{total} \times (1/2)$	$B_{total} \times (1/2)$

for case 1 and case 2 show in Fig. 3 and 4 respectively. We can observe from Fig. 4 that the average number of admitted users of *Algorithm 1* is close to that of the exhaustive search algorithm. In addition, results show that when R_{target} is high, our *Algorithm 1* slightly outperforms the exhaustive search algorithm. Furthermore, from the Fig. 3 and 4, we can conclude that optimal bandwidth allocation between eMBB users and URLLC user is leading to a higher number of eMBB users admitted while satisfying the reliability and latency requirement of URLLC users.

Further, we evaluate average number of admitted eMBB users versus number of URLLC users in Fig. 5. Results
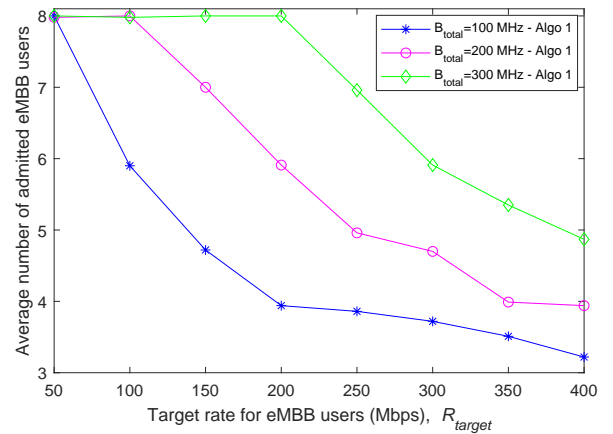

Fig. 3. Admitted eMBB users versus target rate for eMBB users for case 1.
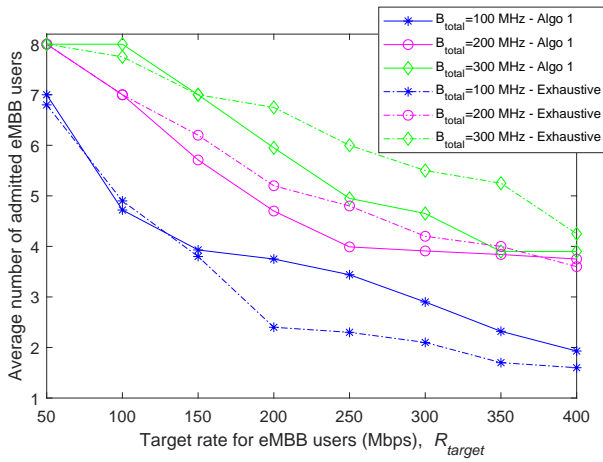
Fig. 4. Admitted eMBB users versus target rate for eMBB users for case 2.

show that even though the number of admitted eMBB users tends to decrease with the increase of URLLC users, optimal bandwidth allocation allows to have more eMBB users in the system while giving resources to the all URLLC users who have satisfied reliability and latency requirements.
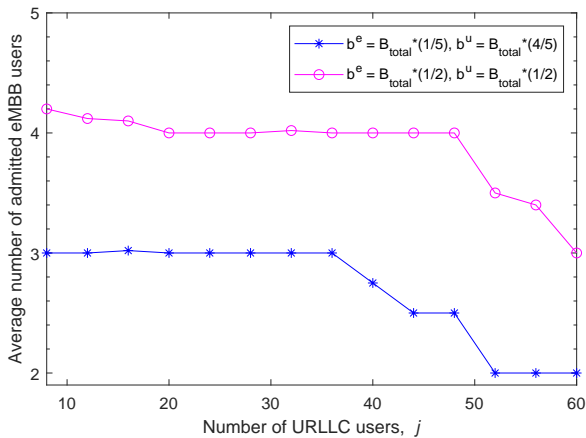

Fig. 5. Admitted eMBB users versus number of URLLC users in the system.

V. CONCLUSION

We have considered the admission control problem in 5G networks where eMBB users and URLLC users are coexisting. URLLC users are time and mission critical while eMBB users need high data rates. Thus, for the coexistence of both URLLC and eMBB users, we need to control the admissions of eMBB users and facilitate scheduling all the URLLC users. In this paper we have proposed an admission control algorithm to maximize the number of admitted eMBB users to the system, who have sufficient data rate, while allocating power, bandwidth and beamforming directions to all URLLC users whose latency and reliability requirements are always guaranteed. The proposed admission control algorithm is formulated as an ℓ_0 minimization problem. It is based on ℓ_0 approximation

methods and sequential convex programming. Numerically we have shown that the proposed algorithm achieves near-optimal performance. From the numerical results, we can conclude that our system can maximize the possible number of admitted eMBB users with required data rate when all URLLC users have satisfied their reliability and latency requirements. Optimal bandwidth, power and beamforming directions allocation between eMBB users and URLLC user is leading to a higher number of eMBB users admitted. This research can be extended to address multi-cell scenario and user mobility.

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