Joint QoS-Aware Downlink and Resource Allocation for Throughput Maximization in Narrow-Band IoT with NOMA

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Abstract. Narrow-Band Internet of Things (NB-IoT) is 3GPPs cellular technology designed for Low-Power Wide Area Network (LPWN) and it is a promising approach that NB-IoT combines with NOMA which is designed for accommodating more devices in the 5G era. Previous works mainly focus on uplink channel resource allocation to achieve connectivity maximization in NB-IoT with NOMA; however, few articles consider NB-IoT downside issues and downlink resource allocation problem to achieve maximum system throughput has not been studied in NB-IoT with NOMA. Thus, in this paper to provide a reliable and seamless service for NB-IoT users (NUs) and maximizing network downlink throughput, we propose a resource allocation algorithm for joint equipment QoS requirements and resource allocation fairness. In this scheme, we design algorithm to implement the mapping between NUs and subchannels for suboptimal system throughput. Then we convert the power allocation problem of the NUs on the same subchannel into a DC problem and we design algorithm to solve it to get suboptimal solution. Numerical results show that the proposed scheme achieves a better performance compared with exiting schemes in terms of the system throughput.

Keywords: Narrow band internet of things · Downlink resource allocation algorithm · Quality of service (QoS) · Throughput maximization

1 Introduction

Internet of Things (IoT) has been adopted to incorporate the digital information and the real world of devices. By 2020, it is expected that the IoT connections in the world will reach tens of billions level, far exceeding the number of concurrent personal computers and mobile phones; moving forward to 2024, the overall IoT industry is expected to generate a revenue of 4.3 trillion dollars which come

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from different sectors such as device connectivity, manufacturing, and other value added services [1]. Low-Power Wide Area Network (LPWN) represents a novel technology to enable a much wider range of IoT applications and complete short-range wireless technologies [2]. The most viable LPWN technology for tomorrow's need is the capability to download data to devices, in future even more so than today [3]. Narrow-Band Internet of Things (NB-IoT) is 3GPP's cellular technology designed for Low-Power Wide Area Network (LPWN). NB-IOT has been designed with the following performance objectives: extended coverage, support for massive devices, support delivery of IP and non-IP data, low cost of device, low deployment cost, low power consumption [4].

However, a single NB-IoT carrier spans one PRB in uplink and downlink. Considering the large-scale of NB-IoT users (NUs) requesting resources, it may degrade the network performance. Lots of works have been done for better network performance. In [5], the author proposes an interference aware resource allocation for NB-IoT by formulating the rate maximization problem considering the overhead of control channels, time offset, and repetition factor. The authors in [6] put forward a classification Back-off method to classify different types of devices in the Back-off mechanism to improve system capacity. In [7] a low area interleaver which is an important component of turbo coding is implemented to achieve the required error correction with 5% area saving by sharing resources. However, the above work just improved the performance of the NB-IoT network from the implementation, but it does not fundamentally solve the problem of insufficient bandwidth resources. In [8], the author proposes a powerdomain uplink non-orthogonal multiple access (NOMA) scheme which allows multiple MTCEs to share the same sub-carrier to achieve large-scale equipment access through allocating sub-carriers. However, the author did not consider the downlink of the NB-IoT network and the impact of NOMA on the network downlink whose base station has the same transmit power. And to some extent, it aggravates the downlink resource allocation problem which is carried out in [9]. Therefore, these aspects will be included in our work of downlink resource allocation in NB-IoT.

In this paper, we focus on the resource allocation in downlink NB-IoT with NOMA for throughput maximization. We propose joint QoS-aware downlink and resource allocation algorithm consisting of subchannels allocation algorithm and subchannels power allocation algorithm that satisfy NUs QoS requirements and ensure the fairness. In our algorithm, we firstly assign subchannels to NUs from a global optimal point. Then we convert the power allocation problem to DC representation and get suboptimal solution. Through the simulation, we can get that our algorithm has better performance than the traditional.

The remainder of our work is organized as follows. Section 2 gives the system model and problem formulation. In Sect. 3, the proposed optimization algorithm is developed. Simulation results and discussions are given in Sect. 4. Finally, we conclude this paper in Sect. 5.

2 System Model

Consider the downlink of a multi-user communication NB-IoT network including single base station (BS) as shown. The SIC is applied at the received of NUs and active NUs share a system bandwidth of one PRB for downlink data transmissions (Fig. 1).

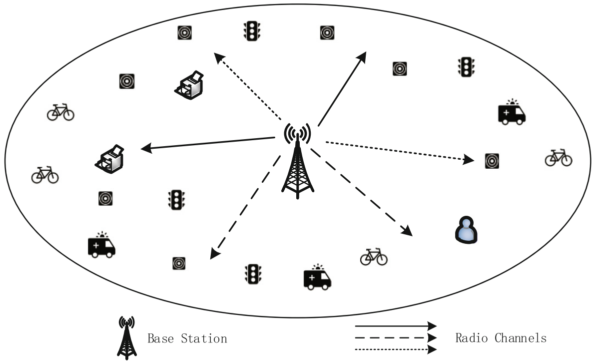

Fig. 1. System model of NB-IoT network with NOMA

We denote u as index for uth NU in the set of U NUs, which is expressed as $u \in \{1, 2, ..., U\}$. Each NU has a downlink rate demand r_u which is no more than r_{max}. However, r_{max} is equal to 0 for NUs without rate requirements. And we denote n as index for nth subchannel in the set of N subchannels, which is expressed as $n \in \{1, 2, ...N\}$. Moreover U NUs are uniformly distributed in a circular region D. According to NB-IoT standard we can get that the bandwidth of the system is BW equaling 180 kHz and the constraint of the bandwidth of subchannels B is expressed as $B = 15$ kHz, so we can get $N = BW/B$. Moreover, each NU can only assign one subchannel. Let $K_n \in \{K_1, K_2, ..., K_N\}$ be the set of NUs allocated on the subchannel n, so we can get $K_n = \{k_{1,n}, k_{2,n}, ..., k_{m_n,n}\}$ where m_n means the number of NUs allocated to subchannel n and the $k_{i,n} \in \{1, 2, ...U\}$ means the ith NUs on the subchannel n. And the power which allocated to NU u on subchannel n is expressed as $p_{u,n}$. We denote P and p_n as the total transmitted power of the BS and the total power allocated to subchannel n.

2.1 Communication Model

For the purpose of throughput-maximum, we consider incorporate NOMA technology into the NB-IoT downlink network. Moreover, successive interference cancellation (SIC) precess is implemented at NU receiver to reduce the interference form other NUs on the same subchannel. We assume that the blocking fading of the channel is taken into consideration with the assumptions that it remains the same within a subchannel and it varies independently across different subchannel.

According to decoding order, the NU $k_{i,n}$ on the subchannel n can be successfully decoded and remove the interference symbols from NUs $k_{j,n}$ with $j > i$. And the interference symbol from NUs $k_{j,n}$ with $j < i$ will be treated as noise by NU $k_{i,n}$. Therefore the SINR of User $k_{i,n}$ with SIC at receiver is denoted as

$$SINR_{k_{i,n},n} = \frac{p_{k_{i,n},n} H_{k_{i,n},n}}{1 + \sum\limits_{j=1}^{i-1} p_{k_{j,n},n} H_{k_{i,n},n}}. \tag{1}$$

where $H_{u,n}$ is the channel response normalized by noise (CRNN) of NU u on subchannel n expressed as

$$H_{u,n} = |h_{u,n}|^2 / noise_n. \tag{2}$$

where $h_{u,n} = g_n.PL^{-1}(d)$ is the coefficient of subchannel n from the BS to NU u in which g_n is assumed to have Rayleigh fading channel gain and $PL^{-1}(d)$ is the path loss function between the BS and NU u at distance d, $noise_n = \sigma_n^2$ means the additive white Gaussian noise (AWGN) with zero mean and variance σ_n^2.

Consequently, the sum rate $R_{k_{i,n},n}$ of NU $k_{i,n}$ on subchannel n through the allocated resources can be expressed as

$$R_{k_{i,n},n} = B \log_2 \left(1 + SINR_{k_{i,n},n}\right). \tag{3}$$

And the achievable sum rate R_n on subchannel n can be expressed in terms of the aggregate rate of NUs allocated the same subchannel n. It is

$$R_n = \sum_{i=1}^{m_n} R_{k_{i,n},n}. \tag{4}$$

In the rest of paper, we simply represent downlink NB-IoT network using NOMA technology with SC and SIC to maximize system throughput in the event of NU's downlink demand.

2.2 Problem Formulation

The implementation complexity of SIC at the receiver increases with the maximum number of the NUs allocated on the same subchannel. In order to keep the receiver complexity comparatively low and restrict the error propagation, we consider the simple case where no more than two users can be allocated on the same subchannel, so the sum rate of subchannel can be expressed as

$$\begin{aligned} R_n = B \log_2 \left(1 + p_n \alpha_n H_{k_{1,n},n}\right) + \\ B \log_2 \left(1 + \frac{p_n (1-\alpha_n) H_{k_{2,n},n}}{1 + p_n \alpha_n H_{k_{2,n},n}}\right), \alpha_n \in (0,1]. \end{aligned} \tag{5}$$

where α_n is the proportional factor to allocate power among the two NUs on subchannel n.

In this paper, the objective is to maximize the system throughput that meet the QoS requirements of NU. For above purpose, we formulate it as an optimization problem which consist of channel assignment and power allocation. We formulate the throughput problem as

$$\begin{aligned} &\max \sum_{i=1}^{N}\sum_{j=1}^{m_i} R_{k_{j,i},i} \\ \texttt{s.t.}\quad & C1: k_{j,i} \in \{1,2,...,U\} \quad \forall j,i \\ & C2: R_{k_{j,i},i} \geq r_{k_{j,i}} \quad \forall j,i \\ & C3: m_i \in \{1,2\} \quad \forall i \\ & C4: \sum_{i\in K_n} p_{i,n} \leq p_n, \sum_{n=1}^{N} p_n \leq P. \end{aligned} \tag{6}$$

The problem 6 is a mixed-integer non-liner programming problem, which is extremely difficult to derive a globally optimal solution with low computation complexity. Because of the above, we assume that equal power is allocated to subchannels and propose a novel resource allocation algorithm to solve it which is show below.

3 Proposed Algorithm

As aforementioned, to obtain the optimal solution of 6, we propose a joint QoS-Aware downlink and resource allocation algorithm. Considering the limited resources of the system, we will select $U = 2N$ downlink users randomly from downlink users. Taking into account the fairness of equipment resource allocation, We set a priority parameter i_u for each NU u which increases as the number of resource allocation failures increases and is used for channel resource allocation. Based on the priority of the device we update the CRNN parameter, so we can get

$$H_{u,n}^{'} = \left(\frac{i_u U}{\sum_{u\in U} i_u}\right)^{\beta} H_{u,n}, \quad \alpha \geq 0. \tag{7}$$

where β is used to adjust the balance between fairness and system throughput.

The design idea of the algorithm is to allocate the device to specific subchannels and calculate optional proportional factor (α_n) in the event of NU's downlink rate requirements. We assume that the system allocates equal power to each subchannel so $p_n = P/N$. Moreover, we consider that all subchannels of NB-IoT network is available, but it is also feasible in portion of the system resources available scenes.

Algorithm 1 Dynamic Suboptimal Subchannel Allocation Algorithm

Input: BW, B, P, U, N, K_N, $H_{u,n}$, $H^{'}_{u,n}$, Av_u, p_n, r_u, $\forall n \in \{1, 2, 3, ..., N\}$,$\forall u \in \{1, 2, 3, ..., U\}$
Initialization:
(a)Initialize BW, P, B, U, r_u , and let $K_n = \varnothing$;
(b)Initialize the set of NUs Re_{un} to record NUs who have not been allocated;
(c)Calculate p_n, N, $H_{u,n}$, $H^{'}_{u,n}$, Av_n;
while Re_{un} is not empty **do**
  for each $u \in Re_{un}$ **do**
    if $|Av_u| = 0$ **then**
      Remove the NU u from Re_{un}; continue;
    end if
    Get $n = arg \max\limits_{H_{u,n} \in Av_u} H_{u,n}$;
    if $|K_n| = 0$ **then**
      Remove the $H_{u,n}$ from Av_u and the u from Re_{un};
      Add the NU u to K_n; continue;
    end if
    if $|K_n| > 0$ **then**
      step1: Remove the $H_{u,n}$ from Av_u;
      step2: Find out all the combinations that have one or two NUs as a set. Then calculate the most appropriate power factor α_n for each collection by the algorithm 2;
      step3: According to the parameters α_n calculated in step2, we recalculate the downlink rate obtained for each combination where parameter $H^{'}_{u,n}$ is used instead of $H_{u,n}$. Then get combination K_{result} satisfying maximum subchannel n downlink rate from all above updated downlink rates of combinations;
      step4: Get K_n according the combination choose in step3. Remove the allocated users from Re_{un} and the unallocated users to Re_{un}.
    end if
  end for
end while
Calculate the system throughput R_{all} according to 6.
Output R_{all}.

3.1 Subchannels Allocation Algorithm

Assuming no more than two NUs can share the same subchannel due to the complexity of decoding and NU's downlink QoS requirements. We denote the subchannels which have not been paired with the NU u as Av_u and whose initial value can be expressed as

$$Av_u = \{H_{u,1}, H_{u,2}, ..., H_{u,N}\},\ \forall u \in \{1, 2, ..., U\}. \tag{8}$$

Based on the perfect channel state information, we can easily get that the NU u can get better performance on subchannel i than on subchannel j if $H_{u,i} > H_{u,j}$.In the rest of the subsection, we propose a suboptimal algorithm named as dynamic suboptimal subchannel Allocation Algorithm (DSSA) for the problem above, as shown in Algorithm 1.

Algorithm 1 describes the proposed DSSA to maximize the system's throughput in the case of ensuring the fairness of resource allocation and satisfying the QoS requirements of the NUs. In lines 1–2, we have initialized the algorithm's input variables according to NB-IoT standards and actual scene requirements. In lines 3–7, we guarantee that the algorithm will be terminated if all devices have already been allocated to the channel or if the device does not find the desired subchannel meeting the requirements. In lines 9–11 it considers how to handle in the absence of equipment allocated to the subchannel. And the other conditions considered in lines 12–17 where step 4 ensures Fairness by using updated $H'_{u,n}$.

3.2 Subchannel Power Allocation Algorithm

The main idea of this subsection is to design power allocation algorithm for maximizing downlink subchannel rate. We propose a algorithm named as QoS-Aware power allocation algorithm (QAPA) as shown in Algorithm 2 to solve problem above.

To realize the maximum throughput of the subchannel without considering the QoS requirement of the NU. Let's assume that there are two NUs $k_{1,n}$ and $k_{2,n}$ allocated on the subchannel n. The problem above of finding α_n to maximize throughput of subchannel n can be restated as

$$\begin{aligned} \max B\log_2\left(1+p_n\alpha_n H_{k_{1,n},n}\right)+ \\ B\log_2\left(1+\frac{p_n(1-\alpha_n)H_{k_{2,n},n}}{1+p_n\alpha_n H_{k_{2,n},n}}\right), \alpha_n\in(0,1]. \end{aligned} \tag{9}$$

Algorithm 2 QoS-Aware power allocation algorithm

Input: denote c_{in} as the input NUs combination, denote $user$ as NUs in c_{in}, p_n
if $|c_{in}| == 1$ **then**
  Calculate the downlink rate of NU $user1$ r'_{user1}, when $\alpha_n = 1$;
  if $r'_{user1} \geq r_{user1}$ **then**
    Set $\alpha_n = 1$;
  end if
end if
if $|c_{in}| == 2$ **then**
  Calculate the optimal solution α_n through algorithm 3;
  Calculate the downlink rate of two NUs r'_{user1} and r'_{user2} allocated subchannel;
  if $r'_{user1} \geq r_{user1} \&\& r'_{user2} \geq r_{user2}$ **then**
    Set α the value calculated through algorithm 3;
  end if
end if
Output α_n.

The problem 9 is solved through DC planning approach. First We transform the formula 9 into a formula for the general definition of DC planning problem that is denoted as

$$\min \quad f(\alpha_n) = m(\alpha_n) - g(\alpha_n), \alpha_n \in (0,1]. \tag{10}$$

where $m(\alpha_n) = -B\log_2\left(1 + p_n\alpha_n H_{k_{1,n},n}\right)$ and $g(\alpha_n) = B\log_2\Big(1 + \frac{p_n(1-\alpha_n)H_{k_{2,n},n}}{1+p_n\alpha_n H_{k_{2,n},n}}\Big)$. We can easily get

$$\bigtriangledown^2 m(\alpha_n) > 0 \quad and \quad \bigtriangledown^2 g(\alpha_n) > 0, \tag{11}$$

so we can prove that 10 can be solved using DC planning approach.

We convert the above-mentioned constrained DC planning problem into an unconstrained DC programming problem. We denote the representative function of α_n as

$$I(\alpha_n) = \begin{cases} 0, & \alpha_n \in (0,1] \\ +\infty, & \alpha_n \notin (0,1], \end{cases} \tag{12}$$

so the problem can be expressed as

$$F(\alpha_n) = f(\alpha_n) + I(\alpha_n) = M(\alpha_n) + G(\alpha_n). \tag{13}$$

where $M(\alpha_n) = m(\alpha_n) - I(\alpha_n)$ and $G(\alpha_n) = g(\alpha_n)$. Then we can denote conjugate function of function M and G as

$$M^*(\beta_n) = sup\{\beta_n^T\alpha_n - M(\alpha_n)|\alpha_n \in (0,1]\}, \tag{14}$$

$$G^*(\beta_n) = sup\{\beta_n^T\alpha_n - G(\alpha_n)|\alpha_n \in (0,1]\}. \tag{15}$$

Finally, We use difference of convex functions algorithm (DCA) to solve 13. The detail steps about DCA algorithm is shown in Algorithm 1, through which we can acquire α_n.

Algorithm 3 Solution for Subchannel Power Allocation

1: **Initialization:**
   Initialize $\alpha_n^{(0)}$, $\beta_n^{(0)} \in \partial G(\alpha_n^{(0)})$, $k = 0$, $\varepsilon > 0$;
2: **while** $F(\alpha_n^{(k+1)}) - F(\alpha_n^{(k)}) \leq \varepsilon \quad or \quad \|\alpha_n^{(k+1)} - \alpha_n^{(k)}\| \leq \varepsilon$ **do**
3: Define convex approximation as
4: $P(\alpha_n) = M(\alpha_n) - G(\alpha_n^{(k)}) - (\alpha_n - \alpha_n^{(k)}, \beta_n^{(k)}), \alpha_n \in (0,1]$ and
5: $D(\beta_n) = G^*(\beta_n) - M^*(\beta_n^k) - (\alpha_n^{(k+1)}, \beta_n - \beta_n^{(k)}), \alpha_n \in (0,1]$;
6: Solve the convex problem. We can get $\alpha_n^{(k+1)} = arg\min P(\alpha_n)$ and $\beta_n^{(k+1)} = arg\min D(\beta_n)$;
7: $k \leftarrow k+1$;
8: **end while**
9: **Output** α_n.

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4 Simulation Results and Discussion

In this section, some simulation results are presented to illustrate the performance of the proposed algorithm. The simulation assumptions that nearly follows 3GPP standards [10]. The NUs are distributed uniformly in the area of $1000 \times 1000\,\mathrm{m}^2$. The full 180 kHz bandwidth, i.e. 12 subchannels at 15 kHz subchannels spacing in downlink, is used for analysis. The wireless channel is modeled as Rayleigh fading channel including pathloss, where the channel coefficient is $h_i^2 = h_0^2 L_i^{-\kappa}$, where L_i^2 is the distance between AP and user i. The pathloss exponent $\kappa = 4$ and h_0 is the complex Gaussian channel coefficient. Moreover, we assume that BS transmit power is 32 dBm and BS cable loss is 3 dB. We consider additive white Gaussian noise with power spectral density −174 dBm/Hz and noise figure of 5 dB. In addition, we can easily get that most NUs in a NB-IoT network are rate insensitive devices so we set two-thirds of the NUs does not have a rate requirement and the other have the downlink rate requirement. We compare the performance of the following algorithms in this simulation:

– Proposed scheme: The resource allocation that jointly considering NU's QoS requirement and the fairness with for NB-IoT NOMA.
– OFDMA scheme: Each subchannel can only be allocated one NU and the power allocation is equal on each subchannel [11].
– NOMA-EQ: The subchannel allocation is same with the proposed scheme but equal power allocation scheme replaces our proposed QoS-Aware power allocation scheme.

Figure 2 illustrates the performance (System Throughput) versus the number of NUs. In the simulation the number of NUs is from 0 to 32 in one base station (BS) and the downlink rate requirement is assigned from [80, 120] kbps. As indicated in Fig. 2, we can get that the proposed scheme improves system throughput by nearly 20% compared to NOMA-EQ scheme and compared to OFDMA scheme the system throughput is improved by nearly 65%. First, the system's throughput increases with the number of devices because system resources are not saturated. Then, Three schemes eventually converge because of limited system resources. Moreover, Algorithm 3 converges earlier than other algorithms because NOMA is not used resulting in supporting fewer NUs.

Figure 3 illustrate the number of successfully served NUs versus total users. In the simulation the number of NUs is from 0 to 32 in one base station (BS) and the downlink rate requirement is assigned from [80, 120] kbps. And we can find that compared with other schemes the number of devices that the system can successfully serve the most under the scenario where proposed scheme is used. In Fig. 3, it can be observed that the proposed scheme and NOMA-EQ scheme perform much better than OFDMA scheme. Moreover, the proposed scheme improves successfully served NUs by nearly 10% compared to NOMA-EQ scheme, because the system cannot meet the downlink demand of some NUs when the power is evenly distributed.

Figure 4 illustrates the impact of the NUs QoS requirement on the system throughput. Here, 32 NUs are deployed in the range and we

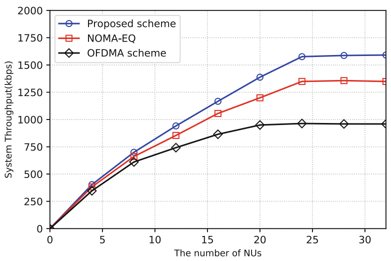

Fig. 2. The system throughput versus the number of NUs.

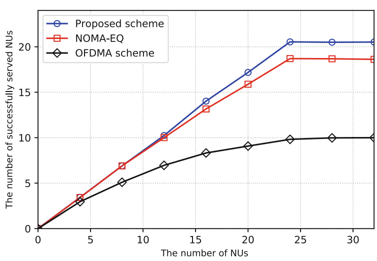

Fig. 3. The number of successfully served NUs versus total users.

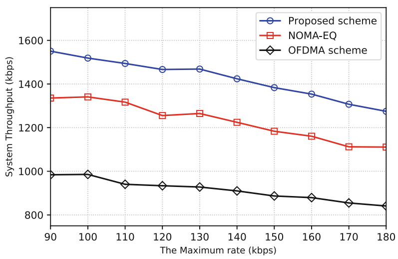

Fig. 4. The system throughput versus the NU QoS requirement

consider that the maximum rate takes the values $(90, 100, 110, 120, 130, 140, 150, 160, 170, 180)$ kbps. In Fig. 4, as the maximum rate continues to increase system throughput continues to decline. However, it can be observed that the proposed scheme still performs better than NOMA-EQ scheme and OFDMA scheme.

5 Conclusion

In this paper, we focus on the issue of downlink in NB-IoT network with NOMA. In order to maximize downlink throughput of NB-IoT network with NOMA, we propose a scheme with the consideration of NU's QoS and the fairness of resource allocation. First, we propose an algorithm called Dynamic Suboptimal subchannel Allocation Algorithm (DSSA) to find the best user-channel matching relationship. Furthermore, to satisfy NU's QoS requirement in DSSA, we propose a QoS-Aware power allocation algorithm (QAPA). Last, in QAPA we transform the power allocation problem between NUs of the same subchannel into a DC problem and the difference of convex functions algorithm (DCA) is utilized to find successive convex approximation. Simulation results prove the system performance has been improved significantly. For future work, to improve the system performance, We will consider joint uplink and downlink system resource allocation in the NB-IoT network with NOMA.

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