A Decomposition Approach for Internet of Things enabled NOMA

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Abstract

Internet of Things (IoT) has been a promising technique in the future network. In IoT, various type of devices is connected. It significantly increases the number of users in the network. However, the limitation on physical resources of current communication technique will reduce the system performance and the Quality of Service (QoS). By applying Non-Orthogonal Multiple Access (NOMA), we can improve the system utilization, also the QoS because NOMA allowed the subcarrier sharing among users. We formulate an optimization problem which minimizes the total transmission time. We then propose an optimal strategy for user association, and total transmission time via decompose fashion of convex optimization. Finally, we use Convex.jl one of the packets in Julia language to solve the optimal solution...

I. INTRODUCTION

The internet of things(IoT) has been introduced in [1]. It significantly improves the capability of connecting the things in physical work with wireless communication. However, the double digits growing of IoT devices has led to the exponential increase of communication devices in the future network [1]. Considering a large number of connectivity demands with limited physical resources which will reduce the Quality of Services(QoS) such as delay, loss, and, overload of the network. A newly communication technology is proposed as non-orthogonal multiple access(NOMA) which allowed multiple users associated in the same resource block [2]. By applying NOMA, the number of users is increasing proportionally with the number of the transmitter in one resource block. Sung et al., [3] studied the optimal game theoretic for power allocation for one pair users in the same subcarrier. The matching algorithm has been proposed in [4] aims to maximize the throughput of the system. Also, there are many cluster algorithm for the dynamic system of IoT device has been studied [5]. However, most of the existing work is considering only two users are using the same subcarrier at the same time. In reality, the IoT sensing data is a small amount of volume, and consume less bandwidth than any other data communication. In this paper, we consider for multiple users are sharing the same subcarrier also allowed a user to communicate through multiple subcarriers. For example, in the figure (1) user 1 is assigned to three different subcarriers to transmit its data. And, in one subcarrier may assign more than one user at the same time: subcarrier 1 have 3 users active {1,2,3}; subcarrier 2 has two users {3,4}. In this paper, we design an optimization problem which decouples between the user association and transmission time. By applying Convex.jl packet of Julia[cite] we will first solve the optimal power allocation. We then calculate the input for stage two and solve the optimal transmission time.

Our paper organize as follows, in section II, we describe our system model and problem formulations. We then using Julia to solve the optimiza-
tion problem described as the section II. In the section III show numerical results of our system model.

II. SYSTEM MODEL AND PROBLEM FORMULATION

We consider a network model consisting of $N$ number of IoT devices denoted as $\mathcal{N} = \{1, 2, \ldots, N\}$, and a single base station. Each IoT device equipped various type of sensors: humidity, and thermometer, etc., which will collected information by the BS via wireless links. On the other hand, there are $K$ subcarriers available at the BS to allocate for users to communicate. In Orthogonal Multiple Access (OMA) at most one user can be allocated in one subcarrier at the fixed time slot $t_n$. Let $S_k = \{0, 1\}$ denoted the number of active user in subcarrier $k$. However, the limitation of physical resource might led the system overload, some user is not able to communicate with BS. By using NOMA, it allowed a number of users sharing the same subcarrier at the same time slot. In this model, we assume the channel gain between IoT devices and BS may different $h^k_i \neq h^j_i$, where $h^k_i$, and $h^j_i$ are the channel gains of user $i$, and $j$ in subcarrier $k$, respectively. Following the Shannon capacity formula, the data rate of user $i$th in subcarrier $k$ is given by

$$ r^k_i = B_k \log_2 \left( 1 + \frac{p^k_i h^k_i}{I^k_i + N_0} \right) $$

(1)

where $B_k$ is the bandwidth of subcarrier $k$, $p^k_i$ is power allocated for user $i$, $I^k_i$ is the interference the user $i$ will see in the subcarrier $k$, and $N_0$ is the noise power. Each IoT device be able to use multiple subcarrier to transmit its data at the same time. In this model, we assume that each IoT device have an amount data to transmit denoted as $x_i$ (e.g., sensing data: thermometer, humidity, etc.) in some periods time, and the available bandwidth is divided in to $K$ subcarrier, equally. In the receiver side (BS), by using Successive Interference Cancellation (SIC) will decode the signals depend on users’ signal. Following the result of [3] the optimal power allocation for any user at the subcarrier $k$ can be calculate as follow:

$$ r^k_i = B_k \log_2 \left( 1 + \frac{p^k_i h^k_i}{\sum_{i=1}^{K} p^k_i h^k_i + N_0} \right) $$

(2)

Therefor, the total transmission time of user $i$ define as follow

$$ \tau_i = \sum_{k=1}^{K} \frac{x^k_i}{r^k_i} = f_k(x^k_i) $$

(3)

where $x^k_i$ is the amount of data user $i$ transmit through subcarrier $k$.

Given a set of $N$ users with its properties, and $K$ subcarriers. The objective is minimum the total transmission time. Therefor the optimization problem can be formulated as follow

$$ \text{minimize} : \sum_{i=1}^{N} f_k(x^k_i) $$

(4)

$$ \text{subject to} : \sum_{k=1}^{K} x^k_i = S_i, \forall i \in N $$

(5)

$$ \sum_{i=1}^{N} r^k_i \leq B_k, \forall k \in K $$

(6)

$$ \sum_{k=1}^{K} p^k_i \leq P_i^{\text{max}}, \forall i \in N $$

(7)

$$ r^k_i \geq \lambda^i_{\text{min}}, \forall i \in N, k \in K $$

(8)

$$ p^k_i \geq 0, x^k_i \geq 0, \forall i \in N, \forall k \in K $$

(9)

Constrain (5) represent for the demand of all users must be served. Constrain (6) represent for the guaranteed capacity of subcarrier $k$ not be able to exceed. Constraint (7) mean the total power allocation of user $i$ is not exceed its capability. The requirement data rate for each user denoted as constrain (8). And, the remaining constraint guarantees the non-negativity of each variable. The optimization problem is the convex problem and all of the constraints are linear. However, the problem is coupling between the transmission time and the number of the active user in the same subcarrier. We then separate the problem in two stages: the first stage is user association, and the second is to minimize the total transmission time. The first stage optimization problem define as follow:

$$ (PO)_{\text{max}} : \sum_{i=1}^{N} \sum_{k=1}^{K} r^k_i $$

(10)

$$ \text{subject to} : \sum_{i=1}^{N} r^k_i \leq B_k, \forall k \in K $$

(11)

$$ \sum_{k=1}^{K} p^k_i \leq P_i^{\text{max}}, \forall i \in N $$

(12)

$$ p^k_i \geq 0, \forall i \in N, \forall k \in K $$

(13)
and the second stage as:

\[(TO)\min_{x} N \sum_{i=1}^{N} f_i(x_i^k)\]  \hfill (14)

subject to \( \sum_{k=1}^{K} x_i^k = S_i, \forall i \in N \) \hfill (15)
\( r_i^k \geq \lambda_{i}^{\text{min}}, \forall i \in N, k \in K \) \hfill (16)
\( x_i^k \geq 0, \forall i \in N, \forall k \in K \) \hfill (17)

III. SIMULATION

In this section, we provide the numerical result which the parameters are described in the algorithm (1).

**Algorithm 1** Minimize total transmission time
1. **input:** \( N, K, H, M \)
2. **Output:** Minimize total delay
3. **Initialization**
4. Solve OP problem by Convex.jl
5. \( r_i^k = B_k \log_2 \left( 1 + \frac{p_i \gamma_{i,k}}{I_k + N_0} \right), \forall i \in N \)
6. Solve TO problem by Convex.jl
7. **return** Optimal value of objective (4)

In the algorithm (1), we initialize value for all variables following: number of users \( N = 100 \), number of channels \( K = 30 \), number of active user in one subcarrier \( L \leq N \), randomize value for channel gains matrix \( H \) follow homogeneous Poisson point process (PPP). After initialization, by applying the convex optimization packet named as Convex.jl [6] will solve the problem OP. Based on the results from the first stage, we then calculate the data rate of each user \( i \) for given input of stage two. In the figure (2), our propose algorithm has out performance of the greedy method, and achive the optimal solution with in 50 iterations.

IV. CONCLUSION

This study shows us that by applying the decomposition algorithm the system will achieve the optimum value of transmission time and resource allocation for all user. Simulations have shown that the proposed algorithm significantly enhances the performance and achieves very fast convergence.

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