Throughput-oriented Power Allocation Scheme Based on Convex Optimization for Cache-Enabled FiWi Access Network in 5G IoT Scenario

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*Abstract*—This paper presents an energy-saving wireless power allocation scheme based on convex optimization in cache-enabled FiWi access networks. By proving that the optimization problem of throughput in cache-enabled FiWi access network can be mathematically formulated as a convex problem in a global view, it can be inferred that with a fixed caching file selection strategy, the solving task of global optimal throughput solution can be mapped to a multi-choice knapsack problem (MCKP). A dynamic programming algorithm in solving the power allocation scheme based on convex optimization (PA-CO) is proposed accordingly. Experiments indicate that the proposed PA-CO improves the global throughput when confronted with large-scale access terminal sets in 5G IoT scenario.

Keywords—FiWi access network, throughput, convex optimization

# Introduction

To cope with the demands brought by the numerous emerging applications such as autonomous vehicles and telemedicine, FiWi becomes the most widely applied access technology with the significant performance of long transmission distance and flexible access ability. In 5G IoT scenario, the sharp increase in the number of access terminals would put higher requirements on the throughput as well as energy consumption in FiWi access networks, which increases the difficulty of solving global optimal power allocation solutions.

The proper distribution of wireless transmit power for different access user devices has been proved to be a NPC problem and has caught the attention of many researchers [2]. The present researches are mainly focused on the wireless access domain [3, 4], which take advantages of several different dynamic programming algorithms and realize the breakthrough of throughput, compared with the fixed and manual assignment methods. However, the influence from the optical transmission domain has not been paid much attention in above studies. In addition, the state-of-the-art caching mechanism of FiWi access network is not fully utilized in giving more impressive achievements.

Motivated by the drawback above, convex optimization, which has the capacity of multi-objective optimization, is regarded to be suitable to involve the constraint from optical domain and caching mechanism into the solving process, in order to achieve a more optimal solution in power allocation.

In this paper, we propose an energy-saving power allocation scheme based on convex optimization (PA-CO) to improve the overall throughput in the scenario of massive access terminal sets in 5G IoT. The proposed PA-CO jointly considers the constraint imposed by optical domain and cache and dynamically adjusts the wireless transmit power distribution to achieve maximum throughput. Meanwhile, PA-CO has the ability to decrease power allocation latency because of the good convergence capacity of convex optimization algorithm. The experiments and simulations demonstrate that the proposed method can improve the total throughput to 91% with large-scale access terminal sets dramatically compared with the method based on fixed power assignment.

# Mathematical Formulation

The architecture of the cache-enabled FiWi access network considered in this paper is shown in Figure 1. Signals are issued by optical line terminal (OLT) through the feeder ﬁber to an optical splitter, which is further connected to multiple optical-network unit-base stations (ONU-BSs) by distribution fibers. Passive optical network (PON) is adopted in the optical domain. In wireless domain, ONU-BSs broadcast signals via wireless links to different user equipment (UE).

As the interface of optical and wireless domains, the ONU-BSs are indexed by a set *N*= {1, 2, ···, *n*, ···, *N*}. Each ONU-BS is cache-enabled, and the maximum caching capacity of ONU-BS*n* is denoted as *Hn* (bits) (*n*∈N). In the coverage area of ONU-BS*n*, the set of user equipment (UE) is denoted by *Φn* and indexed by an index set *J* = {1, 2, ···, *j*, ···, *J*}. Let denotes the maximum power of ONU-BS*n* and denotes the total power consumed by *ONU-BSn*. can get divided



Figure 1. IoT FiWi access network architecture with caches at ONU-BSs

into two parts for backhaul and delivering respectively. The part for wireless signal transmission to *UEj* is denoted as , and the part for caching files is denoted as .The ﬁles are indexed by a set *K* = {1, 2, ..., *k*, …, *K*}. For ﬁle , its size is denoted by (bits). The cache decision on the at *ONU-BSn* is denoted as . More specifically, means that *ONU-BSn* is going to cache the file and vice versa. denote the probability that ﬁles requested by UEs are not cached at *ONU-BSn* (i.e., cache miss ratio).

By jointly considering the caching capacity of each ONU-BS as well as the maximum capacity of PON, the throughput optimization problem is formulated as a mixed-integer programming (MIP) expressed as follows.

P1:

|  |  |
| --- | --- |
|  | (14a) |

s.t.

|  |  |  |
| --- | --- | --- |
|  | | (14b) |
|  | (14c) | |
|  | | (14d) |
|  | | (14e) |

where is determined by the physical structure of the *ONU-BSn* itself and omitted for a constant. The Rayleigh channel gain is denoted by *gnj*, which follows the exponential distribution. N02 represents the power of additive white Gaussian noise (AWGN). C represents the maximum capacity of optical fiber in PON.

Constraint (14b) guarantees that for each *ONU-BSn*, the sum of the power consumed by wireless signal transmission, caching and the circuit should not exceed the maximum power limitation. Constraint (14c) means that the requested transmission rate of the files which are not be cached by all ONU-BSs to the core network should not exceed the channel capacity constraint of PON. Constraint (14d) makes sure that for each *ONU-BSn*, the total number of bits of the cached files should not exceed its maximum caching capacity.

Let

|  |  |
| --- | --- |
|  | (20) |

The Lagrangian of P1 can be given as

|  |  |
| --- | --- |
|  | (18) |

where , ∈ (i = 1, 2, 3) are Lagrangian multipliers.

Obviously,

|  |  |
| --- | --- |
|  | (21) |

which represents that when the allocated wireless transmit power is considered as an independent variable, the objective function of Problem P1 is decreasing and strictly concave. Justified by the same reason, is also a concave function.

Considering the synthesis constraints from the bearer capacity of feeder fiber, the caching capacity of ONU-BS, and the QoS requirements of UE, it can be proved that < 0 , i = 1, 2, 3.

The KKT Conditions of Problem P1 can be expressed as

With an assumed caching file selection strategy, the solution space of problem P1 can be significantly reduced and denoted by

|  |  |
| --- | --- |
|  | (1) |

in which represents the local optimal solution of caching files. The element of A as represents a pair of caching file selection and wireless power allocation schemes that resultantly acts on network throughput. Let denotes whether is chosen to be the solution, where we have .

Let to be the backhaul bandwidth occupied by *ONU-BSn* with respect to solution , where we have

|  |  |
| --- | --- |
|  | () |

Likewise, deﬁne to be the sum rate of UE associated to *ONU-BSn* with respect to solution , where we have

|  |  |
| --- | --- |
|  | () |

Therefore, problem P1 can be reformulated as

P2:

|  |  |
| --- | --- |
|  | () |

s.t.

|  |  |
| --- | --- |
|  | () |
|  | () |
|  | () |

which is in the format of a MCKP.

# Power Allocation Scheme Based on Convex Optimizaiton

In this section, we propose a dynamic programming algorithm for power allocation based on the solution of MCKP as outlined in Algorithm 1, namely PA-CO.

We denote I(n,c) to be the maximum throughput of the IoT FiWi access network. Then the state transition equation can be written as

|  |  |
| --- | --- |
|  | () |

an additional class to calculate the corresponding maximum throughput and the following recursive formula describe how the iteratively method is performed. At each iteration, the optimum solution is determined and updated by () for the given number of classes *n* and bandwidth limitation *c*.

|  |  |
| --- | --- |
| Algorithm1:Dynamic Programming Algorithm for PA-CO | |
| Input: N, J, K, W, , C, , , , ; | |
| Output: , ; | |
| 1: | for UE = 1 to j do |
| 2: | The total number of requests in the previous cycle record -> value |
| 3: | For ONU-AP = 1 to N do |
| 4: | Satisfy the request of the UE whose requested file is on the current cache list |
| 5: | Calculate the remaining available transmission power -> total backpack capacity |
| 6: | For each UE that has not yet fulfilled the request, calculate its required transmission power -> volume |
| 7: | Step 4, 5, 6 constitutes a MCKP. Performs transmission power allocation based on its optimal solution by () |
| 8: | Increase the value weight of UEs that are not satisfied in the second multi-selection backpack problem. |
| 9: | End for |
| 10: | This week's network throughput calculation = (sum of file sizes obtained in 9a + sum of file sizes obtained in 10) / duration of the cycle |

The running time of PA-CO is dominated by the *c* iterations of the second for-loop, each of which contains at most J iterations where a new solution of a subproblem is computed. Considering N ONU-BSs in the IoT FiWi access network, there are N subproblems to be computed, so the overall time complexity is O(NCJ).

# Experimental Assessment and Results Analysis

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# Conclusion

In this paper, we propose PA-CO method based on MCKP in IoT FiWi access network to realize highly accurate power allocation for the promotion of throughput. PA-CO uses the global optimal capacity of convex optimization to full advantage. The experiments show that PA-CO is fully capable to improve the accuracy rates and reduce the time of fault location with large-scale alarm information dramatically compared with the method based on neural network.

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