Difference Based Matching Algorithm for User Association Problem in Ultra-Dense Heterogeneous Networks

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***Abstract*—To meet the ever-increasing requirements of high data transmission rates by Internet of Things (IoT) users, ultra-dense heterogeneous network (HetNet) is introduced for its excellent performance in enhancing cell coverage and improving system throughput. However, the sophisticated structure in ultra-dense HetNet makes user association become a crucial problem. Thus, this paper focuses on the user association problem in ultra-dense HetNet, aiming at maximizing system throughput. Then a difference based matching algorithm is proposed, in which the achievable rate difference between the current request and the next request is taken into account when multiple IoT users compete for the access opportunity with the same low power points (LPPs). Simulation results show that the proposed algorithm can achieve both the highest system sum-throughput and the best fairness compared with the four comparison algorithms.**

I. Introduction

The emergence of Internet of Things (IoT) brings much burden to the existing wireless transmission network [1]. To ensure high-quality services for IoT users, ultra-dense heterogeneous networks (HetNets) are introduced [2], which integrate different kinds of network patterns together as depicted in Fig. 1. By deploying low power points (LPPs) (such as microcell, picocell and femtocell) within the coverage range of the macro-cell access points (MAPs), ultra-dense HetNet can obtain larger coverage and higher transmission rate.

Indeed, ultra-dense HetNet can improve wireless resource utilization efficiency, however, it can make the network structure be more complicated at the same time. The sophisticated network structure will bring an emerging problem, which we call it user association. User association, namely, associating IoT user with a specific access point (AP), which can substantially affect the system performance because it's the beginning of signal transmission. This paper focuses on the user association problem in HetNet, aiming at maximizing system sum-throughput and obtaining better user fairness.

Considering the state-of-the-art user association algorithm, this paper aims to maximize system throughput under the constraint that the LPP' service quota is finite. The formulated model is actually a 0-1 programming problem. Based on the matching game theory used in [3], this paper proposes a difference based matching game, which can achieve higher system throughput and better user fairness.

II. System Model

Here, a ultra-dense HetNet consisting of one MAP, L LPPs, and K IoT users is considered. According to Shannon capacity formula, the achievable data rate of $k(k = 1, \ldots, K)$ that accesses the ith ($i = 0$ indicates MAP, and $i = 1 \ldots L$ indicates LPP) AP can be obtained [4].

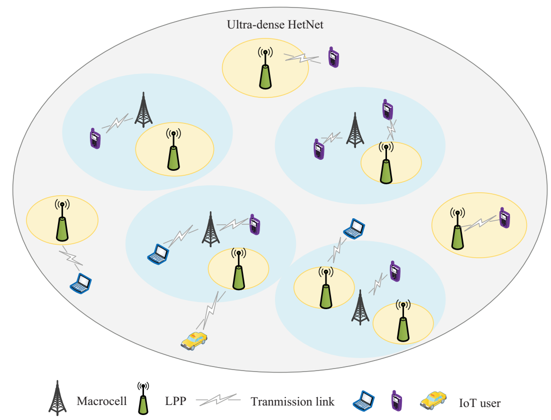

Fig. 1: Ultra-dense HetNets.

Next, aiming for maximum system throughput while considering the service quota of LPP, the formulated optimization problem can be represented by

$$\max \sum\nolimits_{k=1}^{K} R_k = \max \sum\nolimits_{k=1}^{K} \left(\sum\nolimits_{i=0}^{L} x_{ik} r_{ik} \right), \quad (1)$$

subject to:

$$\sum\nolimits_{i=0}^{L} x_{ik} = 1, \forall k; x_{ik} \in \{0, 1\}, \forall i, k; \quad (2)$$

$$\sum\nolimits_{k=1}^{K} x_{ik} \leqslant \lambda_{\max}^{i}, i = 0, 1, \ldots, L. \quad (3)$$

R_k indicates the data rate of user k. $x_{ik} = 1$ indicates the situation that user k associates with AP i, and $x_{ik} = 0$ otherwise. $\lambda_{\max}^{i}$ describes the service quota of AP i.

III. Difference based Many-to-one Matching Algorithm

The problem shown in Section II is NP-hard. To solve the problem in a distributed manner, matching theory is leveraged. However, the performance of deferred acceptance (DA) algorithm in [5] is not satisfying. To further improve system throughput, the difference based matching algorithm is proposed in this paper, as illustrated in Algorithm 1.

Algorithm 1 Difference Based Matching Algorithm

Step 1: Initialization
Initialize AP set AP and IoT user set U. Construct preference list P^i_{AP} and P^k_U for AP and U according to the achievable data rate.
All U_k that haven't be matched are included in set W, $W = U$. Set association matrix $X = [0]_{(L+1)\times K}$.
Step 2: Preliminary Matching
for all $U_k \in W$ **do**
  Update P^k_U, then IoT user U_k send connecting request to the AP that locates in the first place of its preference list;
end for
Step 3: LPPs' Selection
for all $AP_i \in AP - \{AP_0\}$ **do**
  if $\sum_k x_{ik} > \lambda^i_{\max}$ **then**
    Calculate the differences between the optimal and suboptimal rate for these $\sum_k x_{ik}$ users, and sort them in a descending order, which is S.
  end if
  If a IoT user is located in the last $\left(\sum_k x_{ik} - \lambda^i_{\max}\right)$ in S, it will be rejected.
end for
Step 4: Judgement
If $W = \emptyset$, go to step 5; otherwise go to step 2.
Step 5: Termination

TABLE I: Sum-throughput comparison

Algorithms	Sum-throughput (10^7bits/s)	Improvement than MAP-only
proposed algorithm	2.6091	5.15%
Traditional matching	2.5926	4.48%
The best AP	2.5656	3.39%
LPP-first	2.5138	1.31%
MAP-only	2.4814	0

IV. Simulation Results and Analysis

In the simulations, the MAP is at the center of hexagon cell with radius of 500 m, and it owns four LPPs, which are at the center of circular network with radius of 200 m. Besides, the LPPs are non-overlapping, and the LPPs and IoT users are randomly distributed in the network.

First, we compare sum-throughput when $\lambda^i_{\max} = 4$. When total user number equals to 70, the specific sum-throughput comparison results are shown in Table I. From Table I, we can see that the proposed algorithm can achieve 5.15% throughput gain than the MAP-only algorithm. Except for the sum-throughput, user fairness is also compared when $\lambda^i_{\max} = 6$, which is shown in Fig. 2. From Fig. 2, we can see that the proposed algorithm has the highest fairness index amongst the five algorithms. Finally, the influence of LPP's service quota is depicted in Fig. 3. Except MAP-only algorithm, the sum-throughput curves of the other four algorithms grow with the increase of service quota at the beginning. When the LPP's service quota reaches a certain value, the curves keep stable.

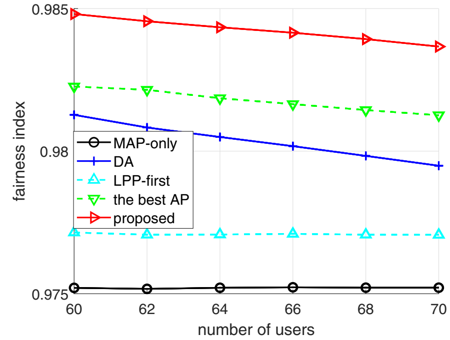

Fig. 2: User fairness.

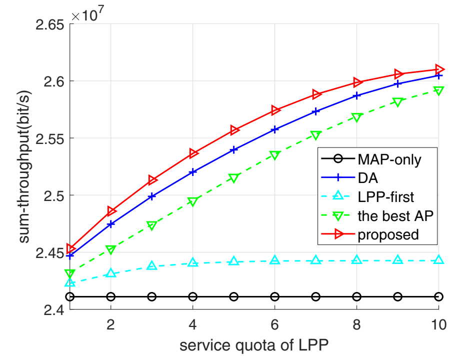

Fig. 3: System sum-throughput.

V. Conclusion

This paper deals with user association problem in ultra-dense HetNets. To obtain better system throughput, a difference based matching algorithm is designed, In the proposed algorithm, the achievable rate difference between the current iteration and next iteration is taken into account when multiple users compete for the same LPP. Simulation results show that the proposed algorithm can achieve both the highest sum-throughout and the best user fairness.

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