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Towards sustainable heterogeneous wireless networks: A decision strategy for AP selection with dynamic graphs

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ABSTRACT

This paper considers a problem of user and access point associations in heterogeneous wireless networks consisting of multiple radio access technologies. The current association policies are mostly based on a selfish user behavior optimizing their own decision criteria. Such simple strategies, however, might fail especially in a congested place with a large number of users. From this perspective, this study propounds a strategy for optimizing the problem that aims at sustainably and fairly maximizing the minimal utility of users. The minimal utilities can be obtained from bare essentials of the quality of experience and defined by considering different requirements of each user. In order to analyze characteristics of the proposed selection strategy, we conduct simulations comparing it with the other selection method under each evaluation criterion. Numerical results suggest that the proposed selection i) enhances the total minimal utility in sustainable and fair manners, ii) indicates a distinctive trend in load balancing and iii) requires a comparable computational time and handover frequency in contrast with the other selection.

1. Introduction

Heterogeneous networking is an emerging paradigm for a wireless network in which network operators can inclusively exploit advantages of different access networks so as to tackle the capacity limitations of the current and next generation of wireless networks. This heterogeneous wireless environment is composed of access points (APs) of different radio access technologies (RATs) such as LTE, 3G, WiFi, and WiMAX [1,2]. In such an environment, multiple APs could be available for mobile users considering rapidly growing AP deployments [3]. Therefore, it is essential to associate with an appropriate AP in order to improve the quality of experience (QoE). The problem to select a destination node for a user is named *AP selection problem*.

From a technical point of view, the AP selection problem is assigning a user to a suitable AP among available access networks to optimize a certain objective function. The current association policies are mostly based on a selfish user behavior maximizing their own throughput [1,4]. With this simple strategy, the overall user utility might be temporarily improved through repeated user associations. However, it may continue for a short time, especially in a crowded place with a large number of users. It should be realized that different users would have different needs since recent applications have their particular quality of service (QoS) requirements [5]. Hence, when all users including undemanding ones unnecessarily select an AP which yields the largest reward, satisfactory APs could be unavailable to demanding users afterward. This finding suggests that such a selection mechanism might be ineffective when applied to the case.

In the light of resource efficiency, it would be desirable to provide *minimal utilities*, which can be obtained from the bare essentials of the QoE, for all users on a sustainable basis rather than provide excessive utilities for a limited number of users. By focusing on the minimal utility, it would be possible to share limited network resources in the longer term. The notion of such *sustainability* is an another significant factor to evaluate the effect of AP selections as well as the minimal utility because network resources are limited especially in congested situations.

As mentioned above, the network congestion in AP selection has been becoming an important and fundamental challenge for today's network management as mobile user densities highly increase in some particular locations. Typical examples include railroad stations or classrooms in campuses. In particular, Japanese train stations are distinguished by their tremendous congestion during commuting rush hours.

The motivation of our study is to establish a strategy for optimizing AP selection on the concept of minimal utility and sustain-

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ability. A network consisting of multiple APs is first modeled with a dynamic graph considering user dynamics. This paper then defines the minimal utility considering user requirements. The users are classified based on different requirements of the running applications. Then, we formulate the problem aiming at the enhancement of the total user satisfactions in sustainable and fair manners. Our selection algorithm is designed using the concept of mutual concession for associations of both newly joining and existing users. Note that our solution does not require any modification of APs. Simulations are conducted to verify the proposed selection comparing it with the selfish behavior approach regarding average and worst minimal utilities, sustainability and fairness in comprehensive and specified situations. Furthermore, we examine these algorithms in terms of common metrics such as load balancing, handover frequency and computational time.

The rest of this paper is organized as follows. Section 2 introduces some related studies. Section 3 presents the system model. Section 4 proposes our selection strategy through defining the minimal utility, formulating the problem and designing the algorithm. Section 5 describes simulation conditions, numerical results and their implications. Section 6 finally draws the conclusions of the paper.

2. Related works

Recently, the AP selection problem has been discussed in many research papers which differ in their decision-making criteria, network structures and probabilities of reassociations. The selection criteria are classified into categories such as i) QoS and ii) user preference. Also, networks can be either single or integrated modes in the following cases: 1) WLAN and 2) mobile networks. The possibility of reassociation means whether existing users dynamically handover to another AP from the current one. The comprehensive surveys for the problem can be found in [6,7].

In the literature, the selfish behavior of users has been theoretically studied comparing it with a signal strength based selection strategy. Aryafar et al. [1] focuses on realistic properties of the heterogeneous network to analyze the user behavior. They consider a model that accounts for the distinct transmission rate of each user and the influence of each user's association on other user's received throughput. In the same direction, such load-aware selection mechanisms are also studied by the work in [4]. The authors conducted system-level evaluations with the detailed models of 3GPP and WiFi RATs. In addition, Xu et al. [8] investigates the worst case performance of the selfish strategy and proposes a selection algorithm aiming at a better worst case performance.

Whereas previous studies focus on optimizing a single criterion such as throughput and consider that all users have the same QoS requirement, the following works consider different requirements of each user. Work by Sun et al. [9] mainly considers resource allocation that aims at maximizing the ratio of required throughput to underlying throughput. A handover reduction is implemented through incorporating channel utilization. Also, Khan et al. [10] investigates a user-centric selection mechanism. The negotiations between users and operators are modeled using a multiple attribute auctioning theory. Furthermore, the multiple QoS criteria for user associations are considered by the work in [11]. Based on Analytic Hierarchy Process, they rank APs calculating weights from available throughput and RTT. Then, the best AP would be greedily selected. In order to actualize such mobility controls with heterogeneities, management protocols have been proposed as usage of heterogeneous networks is increasing, e.g. Mobile IPv6 and Proxy Mobile IPv6 [12,13]. These previous works, however, have not taken into account user activity and dynamics, and few studies have been proposed with consideration for user dynamics. The paper [14] formulates the handover process of users by utilizing Markov chain model and proposes a distributed selection algorithm focusing on different utilities of users in different RATs.

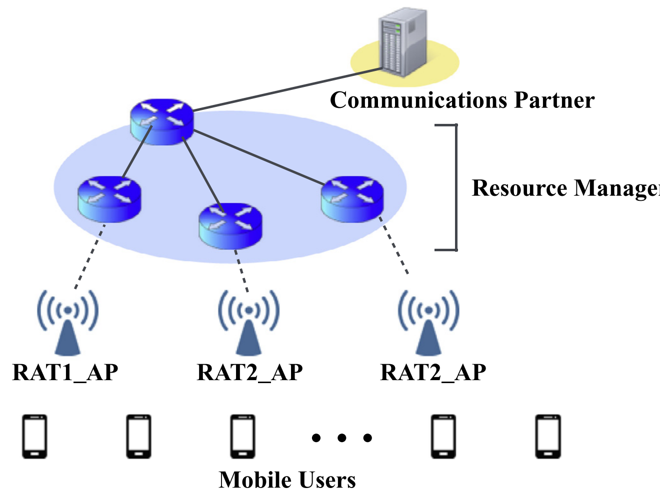

Fig. 1. An example of heterogeneous network.

As has been discussed, notable ideas of selection methods have been suggested in these previous papers. Nevertheless, they have not considered how sufficient user satisfactions can be sustainably and fairly maintained especially when the networks are increasingly crowded. Based on these observations, our research team approaches the AP selection problem considering user dynamics and introduces the concept of minimal utility and sustainability [15,16]. Nonetheless, simple simulations have been conducted with limited conditions in previous studies.

3. System model

This paper supposes the heterogeneous environment with a network resource manager such as Proxy Mobile IPv6 as can be seen in Fig. 1. Mobile users associate with an available AP to access the network and migrate to another one at a certain time through negotiations with the resource manager.

In such an environment, there could be, for example, a local mobility anchor (LMA) which plays a role in an anchor function which switchovers communication paths according to mobile user's domains. There could also be a mobility access gateway (MAG) which plays a role in an agent function which negotiates with LMA about mobile user's mobilities by informing user domain information. This paper does not further discuss specific behaviors of such network managers but focuses on a method to select a suitable AP for user associations from the aspect of resource allocation problem.

4. AP selection strategy

As has been discussed, this paper focuses on sustainably and fairly enhancing the total minimal utilities, i.e. the bare essentials of user satisfactions. Most existing schemes might usually provide substantial satisfactions on average. However, they could fail to ensure minimal utilities of users especially when networks are highly crowded. Based on these observations, this section first models the network considering user dynamics and formally defines the minimal utility as a bounded function. Then, we formulate the AP selection problem based on the minimal utility and design the selection algorithm on the concept of mutual concession to optimize the problem.