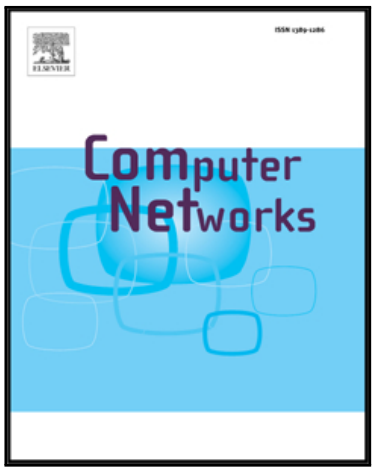

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***Abstract*—Internet of Things has been adopted as an emerging service for future wireless networks, which, however, introduces new challenges for transmission bandwidth and energy guarantees. In this paper, we study the problem of energy cost minimization in heterogenous wireless networks with hybrid energy supplies from the perspective of resource allocation. Owing to the temporal and spatial diversities of user traffic and renewable energy, we propose both centralized and distributed heuristic algorithms to obtain approximate solutions by iteratively addressing the following sub-problems: the total energy minimization problem, green energy allocation problem, user association problem, and green energy reallocation problem. At first, based on the temporal traffic statistics, we obtain estimated average energy consumption profiles for all base stations; Second, we allocate the green energy in the temporal domain for each base station to minimize its energy cost based on its estimated energy consumption profile; Third, in each slot, we perform spatial resource allocation and propose a centralized and a distributed user association algorithm, given the allocated green energy and practical user distribution in each slot. Fourth, after user association and data transmission, we readjust the temporal green energy allocation for each BS to further improve green energy utilization. Simulation results show that compared with two peer algorithms, our proposed solution can significantly reduce the total energy cost.**

***Index Terms*—Energy efficiency, renewable energy, heterogeneous wireless network, resource allocation, Internet of Things.**

I. Introduction

The Internet of Things (IoT) has been becoming an important service in wireless networks owning to its wide range of applications in smart cities, environment monitoring and etc [1], [2]. As more and more objects are connected via radio medium, great challenges have been posed on transmission bandwidth and energy consumption. Envisioning the fast development of IoT with the ever-increasing data traffic, wireless networks have been bound to consume huge energy for data transmission. Particularly, *base stations* (BSs) consume more than 50 percent of the energy, as shown in the breakdown of power consumption, in a typical wireless network. Owning to the huge energy consumption, wireless networks already represent around 0.2% of total carbon emissions, and this is expected to increase every year [3]. How to reduce the energy consumption cost of BSs has become a strategic objective for ensuring the success of IoT in wireless communications industry.

An attractive approach for saving energy in wireless networks is to deploy heterogeneous networks consisting of both macro cells and small cells [4]. Adding more low power pico BSs in macro cells to realize the shorter propagation distances between BSs and end users can achieve 60% reduction of the overall energy consumption, compared with the conventional homogeneous deployment [3]. How to deploy and operate heterogeneous wireless networks in an energy efficient way have been studied recently [5]–[8]. However, these works mainly focus on reducing the on-grid energy consumption.

Another innovative solution is to exploit renewable energy to power BSs for wireless data transmissions with less unit energy cost, such as using solar energy, wind energy and so on [9]. German mobile operator E-Plus [10] has launched the first generation of green BSs by using a combination of solar and wind power. To adapt to dynamics of green power and mobile traffic, a new green energy powered BS mode with five energy related components has been proposed in [11]. In [12], Piro et al. have evaluated the great potential of energy cost and CO_2 emission savings for different scenarios in a heterogeneous green network. However, these studies take into consideration the utilization of green energy according to the known network traffic statistics yet without considering the green energy generation profile.

In this paper, we study the problem of minimizing the energy consumption cost in a heterogeneous wireless network with hybrid energy supplies from the perspective of mobile user association and green energy allocation in both the temporal and spatial dimension. In such a network, BSs can be powered by either on-grid energy or green energy. But due to the circuit constraint, a BS cannot be powered by both energies at the same time. It is generally believed that green energy is much cheaper than on-grid energy. Thus, maximizing the green energy utilization could lead to total energy cost minimization. On the one hand, the charging of green energy like solar power is often with temporal dynamics, and mobile traffic also embodies temporal and spatial diversities. All these factors make the energy cost minimization a very challenging issue.

In this paper, we first formulate the cost minimization problem as a constrained optimization problem. As this problem involves both temporal and spatial optimization of resource al-

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