Ad Hoc Networks 000 (2016) 1–11

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

Energy-efficient mobile relay deployment scheme for cellular relay networks

Hongbin Chen*, Wangfeng Chen, Feng Zhao

School of Information and Communication, Guilin University of Electronic Technology, Guilin 541004, China

A R T I C L E I N F O

Article history:
Received 21 July 2015
Revised 31 May 2016
Accepted 2 August 2016
Available online xxx

Keywords:
Cellular relay networks
Energy efficiency
Spectral efficiency
Mobile relay deployment
Interference graph

A B S T R A C T

In this paper, an efficient mobile relay deployment scheme to select the deployment sites for mobile relay stations (MRSs) from the candidate positions is proposed, aiming at maximizing energy efficiency (EE) while guaranteeing the spectral efficiency (SE) requirement and the coverage constraints of mobile users (MUs). Firstly, an interference graph construction method is proposed to calculate the interference at MUs served by MRSs. Then, the deployment scheme at each observation time is proposed and our framework consists of three main algorithms. The first algorithm based on the extended Hungarian deployment algorithm is proposed to find the optimal solution, i.e., minimum movement distance. In addition, a greedy deployment algorithm and a static deployment algorithm are proposed to compare with the extended Hungarian deployment algorithm. Furthermore, we compare the performance of these algorithms via simulations and analyze the impact of various parameters on the performance. Simulation results demonstrate that the extended Hungarian deployment algorithm can considerably improve system EE compared to the other two algorithms. Moreover, relay switching occurs more frequently and average relay service time reduces with the increase of maximum speed of MUs.

1. Introduction

Recently, green cellular network has drawn great attention and investigation. It was estimated that the information and communication technology industry has contributed to about 2% of global CO_2 emissions and the energy consumed by base stations (BSs) accounts for about 60%-80% of the total network energy consumption [1]. Energy consumption in cellular networks has become an urgent problem to be solved and energy-efficient cellular networks will be a mainstream of future research. In order to handle this problem and improve network performance, the potential solution is to create heterogeneous networks by introducing other kinds of nodes in traditional cellular networks [2], such as pico BSs, femto BSs, and relay stations (RSs).

The relaying technology was once considered to be energy-efficient. The introduction of RSs between the BS and MUs can reduce transmission distance and improve throughput. But we must recognize that, more RSs deployed in cellular networks will bring higher energy consumption. Therefore, it is necessary to study and analyze the impact of deployment of RSs on the system performance.

At present, the investigation of RSs is mainly focused on the deployment of fixed RSs, which can extend the coverage and enhance the throughput. Once fixed RSs are deployed, their positions are no longer change. Many literatures have studied the influence of different deployment parameters on system performance. In [3], the authors proposed closed-form capacity expressions for interference-limited relay channels and used the expressions to determine the capacity of the cellular network, as well as the optimal position and number of relays that maximize the capacity. The problem of optimally placing relay nodes in a cellular network with the aim of maximizing the cell capacity in case of uniform and non-uniform traffic was addressed in [4]. In [5], joint deployment of BSs and RSs that trying to maximize the network capacity under the deployment cost and the coverage constraint was addressed. The authors proved that the problem is NP-hard and proposed a two-stage BS and RS deployment algorithm to obtain sub-optimal strategies. A similar idea was presented in [6], in which the authors proposed a novel cluster-based RS deployment scheme to select the appropriate deployment positions for the RSs from the candidate positions, considering the tradeoff among the network throughput, the deployment cost, and the overall coverage of the system. The authors in [7] considered a throughput-maximizing RS placement problem and formulated this problem as an integer linear programming (ILP). They proved that this problem is NP-hard and proposed a greedy heuristic to provide

* Corresponding author.
E-mail addresses: chbscut@guet.edu.cn (H. Chen), 857208202@qq.com (W. Chen), zhaofeng@guet.edu.cn (F. Zhao).

http://dx.doi.org/10.1016/j.adhoc.2016.08.002
1570-8705/© 2016 Published by Elsevier B.V.

a sub-optimal solution to this problem. The authors in [8] studied the distance-aware RS placement problem in WiMAX mesh networks and presented two approximation algorithms to strategically deploy the minimum number of RSs in order to meet system requirements such as user data rate requests, signal quality, and network topology. For the deployment of multiple relays, the optimal positions of relays were studied for maximizing the reach to the destination subject to the quality-of-service requirement in [9].

In these works, the capacity and coverage performance of relay-assisted cellular networks have been widely studied, while the energy consumption of relay-assisted cellular networks gets little attention. The authors in [10] analyzed system coverage and energy consumption, and proposed a novel cellular network deployment strategy to jointly optimize the density and transmission powers of BSs. The authors in [11] investigated energy-efficient RS deployment, which showed that introducing appropriate number of RSs into cellular networks with proper positions can improve EE without compromising throughput. The authors in [12] presented the cognitive capacity harvesting network, where RSs were deployed to help the data transmission of secondary users. The problem of RS placement was studied to meet both SE and EE constraints. In [13], the macrocell and ultra-dense small cell deployment strategies have been evaluated from the network SE and network EE perspectives, with extreme densification levels, including both indoor and outdoor scenarios.

The deployment of RSs in the above works is static. In the case of the effect of surrounding obstacles or busy durations, fixed RSs are unable to provide high link reliability. Therefore, there have been many research studies that introduced mobile relay nodes in wireless networks to improve system performance. In wireless sensor networks (WSNs), it is difficult to achieve a large data collection rate because sensors usually have limited energy and communication resources. Mobile nodes may also be used as relays [14] that forward data from source nodes to the BS. Several movement strategies for mobile relays have been studied in [15,16]. In order to address this issue, the authors in [14] investigated the throughput capacity of WSNs, where multiple mobile relays were deployed to collect data from static sensors and forward them to a static sink. They also pointed out that the transmission range and the interference have great impact on capacity gain. The authors in [15] proposed using low-cost disposable mobile relays to reduce the energy consumption of data-intensive WSNs, in which MRSs move to different positions and then remain stationary to forward data along the paths from the sources to the BS. They also considered energy consumed by moving mobile relays. The authors in [16] investigated how to deploy mobile sensor nodes with minimum movement to form a WSN that provides both target coverage and network connectivity.

Some earlier works have investigated the deployment of MRSs in cellular networks to improve system performance, in which the MRSs can be classified as mobile user acting as MRS [17–20], RS on vehicles [21], relay robots [22], and mobile nomadic RS [23]. The authors in [17] studied relay selection in multi-hop cellular networks (MCNs) and proposed two mobile relay selection schemes, in which an idle mobile user acts as a RS. In [18], relay selection and resource allocation algorithms were proposed for mobile relay-enhanced cellular networks, which revealed that data rate of the cell-edge users which are far away from the BS and have lower channel gains increases by using MRSs with the proposed algorithms. More importantly, the authors in [19] reported the first experimental field tests, which validated and quantified the benefits of multi-hop cellular networks provided by using MRSs over traditional cellular networks. It is worth mentioning that, the authors in [20] compared the difference between the cellular network architecture with mobile and fixed RSs as well as their performance gain. In terms of increased capacity, MRSs are more advantageous than fixed RSs. Besides, the authors in [21] proposed an adaptive cost-based RS deployment approach to deploy various types of RSs: fixed RSs, nomadic RSs, and mobile RSs, which indicated that the transmission quality and service quality were increased by adding more RSs. In [22], the fundamental problem of finding optimal positions and allocation of relay robots to establish immediate end-to-end wireless communication in an inaccessible or dangerous area was addressed. Our work is inspired by the work in [23], in which the authors defined and studied the minimum mobile relay path selection problem, whose objective is to deploy minimum number of nomadic MRSs to patrol fixed RSs according to their busy durations. The fixed RSs'busy durations were predicted by using Markov chains, which were represented as a weighted graph. The algorithms based on the principles of graph searching, maximum matching, and maximum flow were proposed to solve the minimum vertex-disjoint path cover problem. But they ignored the energy consumed by moving mobile relays and did not consider the positions of MRSs.

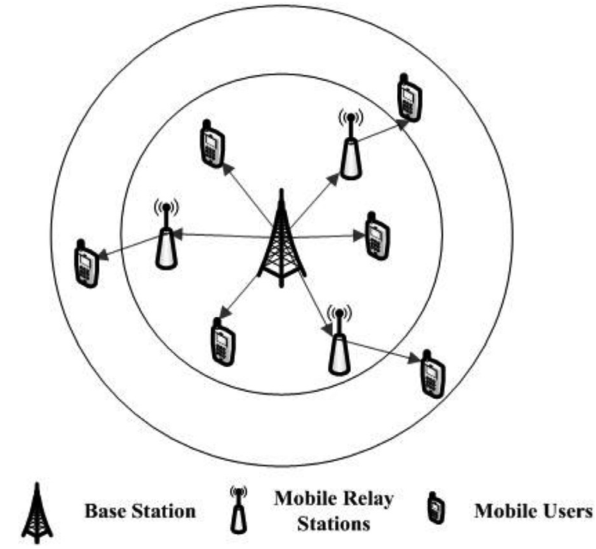

Fig. 1. Downlink transmission in a mobile relay-aided wireless cellular network.

To our knowledge, the EE maximization problem for MRS-aided cellular networks has not been well addressed in literature. Motivated by the above literature and inspired by Liao's work [23], referring to interference analysis in [24] and [25], we firstly analyze the interference at MUs by using the interference graph construction method. Then, in order to maximize the EE at each observation time, we propose an efficient mobile relay deployment scheme in the cellular relay network to select the deployment sites for MRSs from the candidate positions by taking into account the coverage constraints of MUs and the SE requirement.

The remainder of this paper is organized as follows. The system model is described in Section 2. In Section 3, an interference graph construction method is used to analyze the interference at MUs served by MRSs. Furthermore, the MRS deployment scheme and three deployment algorithms are proposed in Section 4. In Section 5, simulation results are presented, followed by some concluding remarks in Section 6.

2. System model

We consider a downlink, two-hop, mobile relay-aided wireless cellular network as shown in Fig. 1. We focus on a single cell with radius R. The BS is located at the center with coordinate $(0, 0)$. The cell is divided into two parts, that is, the inner circle with radius r_0 and the outer ring. At the initial observation time $t = 0$,