Computer Communications 126 (2018) 1–10

Contents lists available at ScienceDirect

Computer Communications

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

Efficient data collection in wireless powered communication networks with node throughput demands

Kaikai Chi*, Yi-hua Zhu, Yanjun Li

School of Computer Science and Technology, Zhejiang University of Technology, Hangzhou 310023, China

ARTICLE INFO

Keywords:
Wireless powered communication network
TDMA
Throughput demand
Convex optimization

ABSTRACT

In the wireless powered communication networks (WPCNs) where nodes are powered by the energy harvested from radio-frequency (RF) transmissions, efficiently scheduling the downlink wireless energy transfer (WET) time and the uplink wireless information transmission (WIT) time is critical to achieve good throughput performance. In this paper, the following type of star-topology WPCNs are considered: each node has its own desired throughput but the throughput demands of all nodes cannot be satisfied due to the nodes' very low energy harvesting rates. For such WPCNs, it is meaningful to minimize the sum throughput-gap. Unfortunately, this requirement cannot be satisfied by the existing data collecting schemes like the sum throughput maximization (STM) scheme. We study the weighted sum throughput-gap minimization (W-STGM) by jointly optimizing the time allocations for the WET and the WITs. Specifically, we first formulate the W-STGM problem as a non-linear optimization problem and prove that it covers the STM problem studied before as a special case, where all nodes have the same throughput weight and the nodes' throughput demands are too high. Second, after proving it is non-convex, we decompose it into two sub-problems: the master problem, which determines the optimal WET time, and the slave problem, which determines the optimal time allocations to WITs for a given WET time. Considering that the slave problem is convex, we develop a dual decomposition method to solve it. Meanwhile, we design a golden section search algorithm to solve the master problem. Simulation results show that, compared to the STM, the W-STGM can satisfy in an adequate manner the throughput demands of the nodes by avoiding node throughput over-provisioning, which wastes system resource, and also increasing the throughput of nodes with large throughput weights by up to several tens of percentage points.

1. Introduction

Traditionally, batteries are used to power the energy-constrained nodes in wireless networks like wireless sensor networks (WSNs). The limited lifetime of batteries prevents these wireless networks to be widely applied in practice. As a promising solution to this problem, energy harvesting [1–4] has recently received a great deal of attention since it may provide unlimited power supply to the nodes by scavenging energy from the environment. However, due to the unpredictable and intermittent nature of conventional renewable energy sources (such as solar and wind), it is challenging to guarantee a certain level of service quality, which makes them only applicable in certain environments [5]. As an energy harvesting technology that overcomes the above limitations, wireless power transfer (WPT) has attracted considerable attention in the wireless research community because it is a controllable and deterministic power transfer method [6]. The WPT techniques mainly include inductive coupling, magnetic resonance coupling and radio frequency (RF) energy transfer. Both inductive coupling and magnetic resonance coupling are near-field energy transfer techniques and moreover they require calibration and alignment of coils/resonators at transmitters and receivers [7]. Therefore, they are not suitable for remote charging. RF energy transfer is a far-field energy transfer technique, which is suitable for powering a larger number of devices distributed in a wide area. It was reported that an energy power of 3.5 mW and 1 uW can be harvested from RF signals at distances of 0.6 and 11 m, respectively, using Powercast RF energy transmitter operating at 915 MHz [8]. The RF energy transfer efficiency can be improved by different techniques, like adaptive energy beamforming [9], highly efficient rectifying antennas [10], etc.

Harvesting energy from the RF signal opens a new avenue for the design and applications of wireless networks [11,12]. Currently, the research on the wireless networks in which the nodes harvest energy from RF transmissions mainly proceeds in two directions. One targets the simultaneous wireless information and power transfer (SWIPT), in which wireless energy transfer (WET) and wireless information transmission (WIT) are simultaneously conducted with the same signal, i.e.,

---

* Corresponding author.
E-mail addresses: kkchi@zjut.edu.cn (K. Chi), yhzhu@zjut.edu.cn (Y.-h. Zhu), yjli@zjut.edu.cn (Y. Li).

https://doi.org/10.1016/j.comcom.2018.05.003
Received 15 November 2017; Received in revised form 22 March 2018; Accepted 9 May 2018
Available online 16 May 2018
0140-3664/ © 2018 Elsevier B.V. All rights reserved.

the nodes retrieve information and energy from the same signal [13–15]. The other aims at a new type of wireless network termed Wirelessly Powered Communication Network (WPCN), in which the WET and WIT are conducted separately.

Compared to SWIPT, WPCN is easier to implement with a lower hardware cost. WPCNs have been considerably investigated. In [16,17], mobile charging vehicles were employed as the energy transmitters to wirelessly power the nodes in the WPCNs. In [18], the wireless powered cellular network was studied, in which dedicated power-beacons are applied in charging mobile terminals. In addition, the wireless powered cognitive radio network was considered in [19], where active primary users are utilized as energy transmitters for charging their nearby secondary users. In [20], a MAC protocol that optimizes energy transfer to the sensor nodes was presented.

Nowadays, the WPCN with one-hop star topology, referred to as the star WPCN below, is widely investigated. In the star WPCN, the sink node is surrounded by one-hop nodes and located at the center of the network and the nodes harvest RF energy from the wireless signal emitted by the sink. One of the examples of the star WPCN is the healthcare WSN, in which the patients are with the sensor nodes that harvest RF energy from the sink node located several meters away from the sensor nodes so that the patients' physiological information captured by the sensor nodes are quickly delivered to the sink. Therefore, in this paper, we study the star WPCN that consists of one sink node with constant power supply and its one-hop nodes powered by the energy harvested from the RF signal transmitted by the sink. Apart from gathering information as in the traditional WSNs, the sink in the considered WPCN performs the extra important task of providing the nodes with RF energy. Hence, we refer to the sink as the *hybrid sink* (H-sink) in the sequel.

In the WPCN, the throughput of a node can be defined as the amount of data delivered to the H-sink per unit of time (in bps). Obviously, no data are delivered during the WET phase. In addition, in the extreme case when WIT duration is set to zero, the throughput is zero because no time is assigned to deliver data, from which we may obtain the conclusion that the throughput depends on WIT duration rather than WET duration. However, this is not true. The reason is explained as follows. A too small WET duration causes very small transmit power of the node due to the quite limited amount of harvested energy such that the throughput is very low. The extreme case is when WET is set to zero, no data can be delivered, i.e., the throughput is zero, as the node remains in the state of lacking energy. In a word, the throughput at the node depends on both its WET and WIT durations. With a given period of time, if the WET duration is too great, i.e., the H-sink spends much time on transferring energy for the node to harvest sufficient energy, the WIT duration will be relatively small, reducing the throughput. A too small WET duration also reduces the throughput as the node suffers from shortage of energy in information transmission. Furthermore, given the WET duration inside the period, a node's throughput can be surely improved if we allocate a larger WIT duration to the node. However, when a time period is shared by multiple nodes, allocating a larger WIT duration to a node shortens the other nodes' WIT durations, causing their throughputs to decrease. Therefore, it is important to properly and jointly allocate the sink's WET duration and all the WIT durations so that the throughput of whole WPCN is increased. This is why the existing work [21] makes efforts on maximizing the sum of the nodes' throughputs, referred to as the *sum throughput maximization* (STM) in the sequel.

In practice, there exist some WPCN applications in which each node has its own desired throughput, but it may not be feasible to achieve the throughput demands of all nodes due to the nodes' low energy harvesting rates. For such WPCNs, it is meaningful to minimize the sum throughput-gap. Here, the throughput-gap of a node is defined as its demanded throughput minus its actual throughput if this difference is positive and is defined as zero otherwise. Unfortunately, this requirement cannot be satisfied by the existing data collecting schemes like the STM scheme. In this paper, we consider this sum throughput-gap minimization (STGM) problem. Moreover, in the heterogeneous WPCNs, it is often the case that some nodes capture more important data than the other ones and these data are required to be delivered to the sink with higher priorities than the other data. In other words, in these applications, the data captured by different nodes have different priorities which reflect different levels of importance, utility or other metrics. For example, in the previously mentioned healthcare WSN, the physiological information of the patients with serious and dangerous disease has higher priorities so that the key physiological information of these patients must not be missed. We tackle this problem by associating different weights to different nodes' throughputs and study the weighted sum throughput-gap minimization (W-STGM) problem. In practice, weight of data is usually used to reflect levels of importance, utility, price (contribution to the network's revenues), etc. Clearly, the W-STGM problem reduces to the STGM problem when all nodes have the same throughput weight.

The main contributions of this paper are summarized as follows:

1. To meet nodes' different throughput demands as much as possible, we study the W-STGM problem and formulate it as a non-linear optimization problem. We prove that it covers the STM problem which has been studied before as a special case where all nodes have the same throughput weight and the nodes' throughput demands are large enough.
2. We show that the W-STGM problem is non-convex. To make it more tractable, we decompose it into the master problem and the slave problem. The former aims to find the optimal WET duration while the latter focuses on determining the optimal time allocations to WITs for a given WET time. Then we design a golden section search algorithm to efficiently solve the master problem and develop a dual decomposition method to solve the slave problem after we prove it is a convex optimization problem.

The remainder of this paper is organized as follows. Related work is introduced in Section 2. Section 3 presents the considered WPCN model. Section 4 presents the W-STGM problem and its some properties. The algorithm for solving the W-STGM problem is given in Section 5. Simulation results and discussions are presented in Section 6. Finally, we conclude this paper in Section 7.

2. Related work

Recently, the design of data collection schemes for star WPCNs has been considered in the literature. In [21], Ju et al. studied the WPCN as what we consider, where one hybrid access point (H-AP, same as the H-sink) with constant power supply coordinates the wireless energy/information transmissions to/from a set of one-hop nodes without other energy sources. The H-AP broadcasts only wireless energy to all nodes in the DL while the nodes transmit information to the H-sink in the UL using their harvested energy. They studied the STM and the common-throughput maximization (CTM) problems and presented the harvesting-then-transmitting (HTT) transmission mode. Following [21], Liu et al. further considered the STM problem with the constraints that the throughput of each node cannot be smaller than a given value [22]. In [23], we studied the transmission completion time minimization problem of each node transmitting a number of bits to the H-AP. This problem covers the CTM problem as a special case where all nodes have the same amount of bits to transmit. Abd-Elmagid et al. [24] studied WPCNs where nodes are equipped with radio frequency (RF) energy harvesting circuitries along with constant energy supplies, aiming to maximize the sum throughput and maximize the minimum node throughput. Pejoski et al. [25] considered the scenario that the H-sink knows the channel power gains of the following M TDMA frames and optimized the transmit power of H-sink and the time allocation of WET and WITs inside each frame to achieve proportional fair resource

Download English Version:

https://daneshyari.com/en/article/6879936

Download Persian Version:

https://daneshyari.com/article/6879936

Daneshyari.com