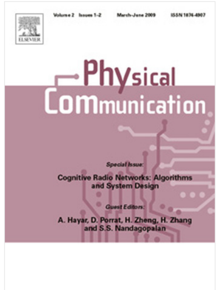
Accepted Manuscript



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PII: S1874-4907(18)30001-6
DOI: https://doi.org/10.1016/j.phycom.2018.03.016
Reference: PHYCOM 518

To appear in: *Physical Communication*

Received date : 1 January 2018
Revised date : 7 March 2018
Accepted date : 30 March 2018

Design of Incentive Scheme Using Contract Theory in Energy-Harvesting Enabled Sensor Networks

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***Abstract*—Wireless energy harvesting (EH) has been proven to be a promising technique for sensor networks to enhance self-sustainability and robustness. Due to the popularity and the inherent mobility, mobile phones will become excellent EH sources for sensor nodes, especially when sensor nodes cannot harvest energy from other fixed ambient sources. In order to motivate ambient mobile phones to transfer power, incentive mechanisms should be provided. Therefore in this paper, a contract-theory based incentive scheme is proposed. Compared to relevant incentive schemes, the proposed scheme not only overcomes the information asymmetry problem caused by privacy-protection nature of mobile users, but has also taken some important characteristics (e.g., time cost of users and remaining capacity of batteries) of mobile users into consideration. Simulation results have shown the feasibility of the proposed contract as well as the effectiveness of the proposed incentive scheme.**

***Index Terms*—Energy harvesting, sensor networks, contract theory, information asymmetry.**

I. INTRODUCTION

RECENTLY, energy harvesting (EH) has drawn wide attention, because it can effectively prolong battery lifetime of wireless devices [1]–[3]. The EH technique has played an important role in energy-constrained wireless networks, especially wireless sensor networks (WSNs). A WSN consists of sensor nodes which can wirelessly communicate with each other and even connect with Internet [4], [5]. Each sensor node is usually equipped with a sensing module, a microprocessor, a wireless transceiver and a power source (e.g., a tiny battery). The limited energy of sensor nodes severely confines the performance of the network [6], [7]. Moreover, it is always not convenient or feasible to replace the batteries for sensor nodes. In order to have enough energy for self-sufficient operation of the network, EH technologies provide a fundamental method for WSNs.

In practice, energy can be harvested from the sources in the environment such as solar, thermal, vibration and radio frequency (RF) sources. Compared to other sources, RF energy harvesting provides main benefits of as low cost and vast availability [8], [9], because our living space has been filled with a sea of radio waves with the explosion of mobile device [10], [11]. The ubiquitous wireless radio signals can be exploited to power sensor nodes in practical WSN applications such as home automation, healthcare, surveillance and transportation. RF energy transfer also has the advantage on transfer distance because of far-field propagation characteristic of radio wave. In [12], a system supporting long-range (above ten meters) energy transfer was demonstrated. In [13], 3.5mW and 1uW of power were harvested from 915MHz radio signals at distances of 0.6 m and 11 m, respectively. In addition, more efficient energy harvesting from RF signals was reported in [14] with the recent design of high efficient rectifying antennas. Thus RF energy transfer is suitable for powering a number of sensor nodes distributed in a large area.

The RF energy sources are generally categorized into two types, dedicated sources and ambient sources. Although dedicated sources (usually fixed) can supply predictable energy to sensor nodes, the deployment of the sources brings high cost to the network. On the contrary, ambient sources are those wireless devices already existing in the environment, such as base stations, wireless access points and mobile phones. Although the energy harvested from mobile phone signals is lower than that from other fixed sources, a significant number of sensors (e.g. RFID tags) only require very small power. For example, in [14], the power consumption of a sensor node was estimated to be between 1 and $20\mu W$. Moreover, with the development of integrated circuits, sensors will become even smaller and consume much less power. In fact, EH through mobile phones have already attracted a lot of research interests because nowadays most people possess at least one mobile phone. The huge quantity of mobile phones, together with their inherent mobility, makes them excellent EH sources for sensor nodes, especially when sensor nodes cannot harvest energy from other fixed ambient sources. In [14], the authors illustrated the possibility of energy harvesting through WiFi and GSM signals from mobile phones. In [15] and [16] efficient EH systems were designed to harvest energy from WiFi signals, while in [17]–[19] energy was harvested from GSM signals. In [20], the power from GSM uplink signals was measured and exploited to power RFID tages. In [21], a novel PENF multiband antenna was designed to harvest energy from 3G signal and 4G signal. In [22], the authors present a design for a broadband L-probe microstrip patch rectenna for RF energy harvesting through UMTS-2100 signal. In [23], the authors forecasted the smart phones as a source of RF energy

This work is supported in part by the National Natural Science Foundation of China (Grant No.61602245, 61771244, 61501238, 61702258), the Nature Science Foundation of Jiangsu for Distinguished Young Scientist under Grant BK20170039, the Natural Science Foundation of Jiangsu Province (Grants No. BK20150791, BK20150786), Fundamental Research Funds for the Central Universities (No. 30916011205) and Open Research Fund of National Mobile Communications Research Laboratory Southeast University (No. 2017D04).

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