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Survey Paper

Survey on energy harvesting wireless communications: Challenges and opportunities for radio resource allocation

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ABSTRACT

Green radio communications has received a lot of attention in recent years due to its impact on telecom business, technology and environment. On the other hand, energy harvesting communication has emerged as a potential candidate to reduce the communication cost by tackling the problem in a contrasting fashion. While green communication techniques focus on minimizing the use of radio resources, energy harvesting communication relies on environment friendly techniques to generate energy from renewable resources and on effective use of the stored energy under the condition that there is always energy available when required. Thus, the focus migrates from minimization of energy to optimal time domain 'distribution' of energy, which causes a paradigm shift in radio resource allocation research.

This survey summarizes major research work in the area of energy harvesting resource allocation. Instead of just focusing on the power allocation based on average and maximum power constraints, the random energy arrival process and packet/energy buffering interact in a challenging way to open new research problems. First, we present the fundamental concepts in energy harvesting communications and review recent research work in different wireless network applications. We discuss some quantitative results from the existing literature to explain the state of the art work. The energy cooperation aspect of energy harvesting is addressed in detail which has emerged as an interesting area of research recently. Finally, we conclude by summarizing some open challenges for future research and scope for innovation in this emerging area.

1. Introduction

Traditionally, spectral efficiency and quality of service (QoS) constraints have been the main focus for the network design. However, 5G wireless network design is greatly inspired by energy efficiency aspects. Green communication has attracted a lot of attention due to rising electricity cost for network operation and its adverse effects on the environment because of CO_2 emissions. It is predicted that the overall Information and Communication (ICT) footprint will almost double or even triple between 2007 and 2020 [1,2]. In a mobile network, base stations alone are responsible for 80% of the network's power consumption [3]. A lot of literature focuses on discussing interesting trade-offs and related challenges between energy efficiency and other network performance indicators like delay, bandwidth, etc., [4,5].

Energy harvesting (EH) is a promising solution to combat the energy inefficiency problem. The main idea is to generate energy from the sources which do not cause CO_2 emissions,

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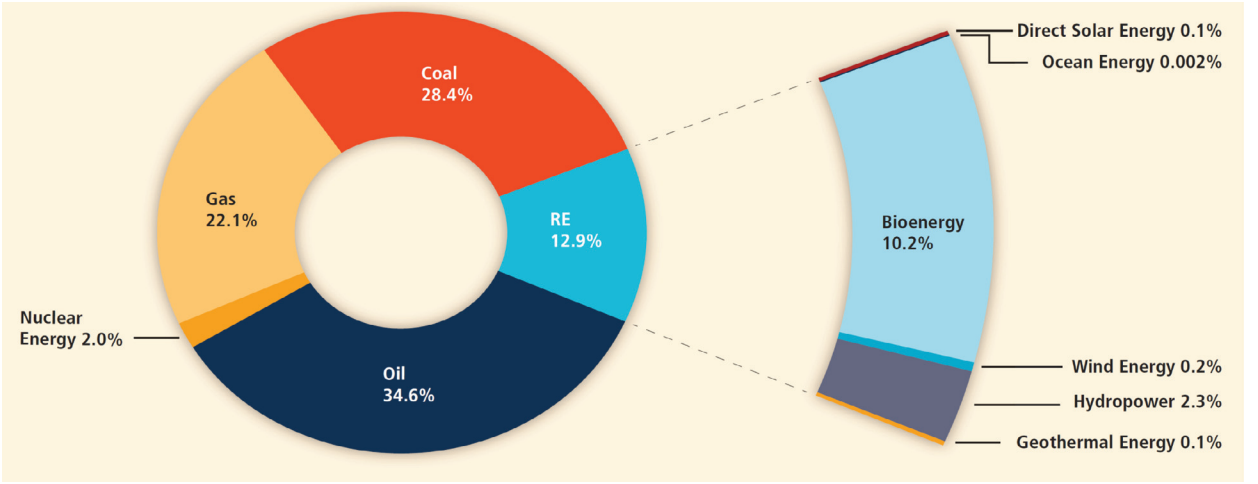

Fig. 1. Shares of energy sources in total global primary energy supply in 2008 [6].

e.g., solar cells and wind turbines. Depending on the geographical location, either one or a hybrid solution serves the purpose well. For example, solar solution suits most of the Asian and African countries where the sun light is available for most of the day time. On the other hand, wind turbine solution is more suitable to central European and Scandinavian countries where the weather is more cloudy and windy. Fig. 1 shows the breakdown of energy sources in 2008 in global primary energy supply [6]. Although, traditional means of energy still dominate yet renewable energy (RE) sources contribute about 13% of the total energy supply. It is worthwhile to mention that capital cost of EH solutions is greater than the traditional continuous power supply or generator counterpart but running cost compensates the cost in a few years of operation. This is really a big advantage for base station deployments in remote areas where regular power supply may not be available or diesel cost for generator is hardly feasible.

In this article, we survey the recent literature available on EH enabled network design and outline the main challenges and opportunities for communication research. As compared to the recent work in [7], where communication techniques for EH wireless communication are addressed by information theoretic point of view, we take a system view of EH communication and classify the research works based on the associated EH models and the areas of applications. We focus more on the resource allocation aspect of the EH wireless communication systems and discuss the future research directions emerging as a result of unpredictable energy supply due to EH sources.

EH brings a few associated challenges for the network designers. In contrast to regular power supply solutions where a fixed amount of power is available throughout the operation, EH solutions are time dependent and energy availability is a stochastic process. For example, the sun light is available throughout the day but not at night. In this case, the harvesting period is constant for a long time. However, energy harvested by wind and other sources may not follow this long pattern of harvesting and harvesting periods may vary stochastically. On one side, it is a must to have

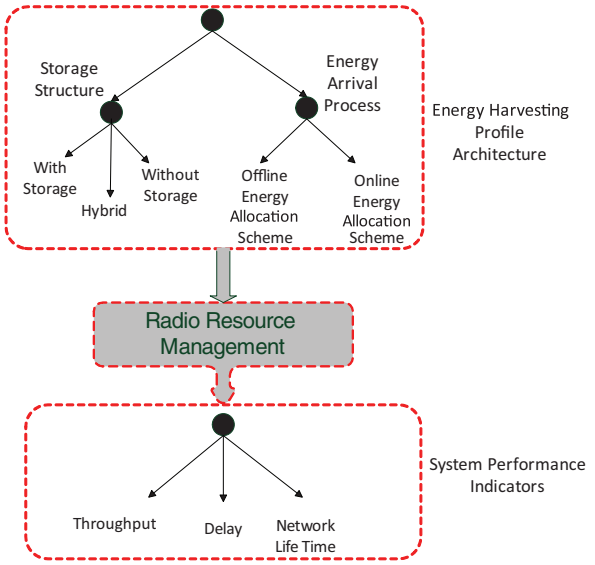

Fig. 2. Radio resource management classification for EH systems.

a mean of energy storage for the time when energy is not being harvested. At the same time, it is important to adapt communication techniques, specially resource allocation mechanisms, such that uninterrupted network operations can be realized. This conversation of energy and adaptation of communication systems according to EH profiles such that energy expenditure is always less than the stored energy at any time is termed as neutrality constraint or causality condition in the literature [8,9]. Thus, energy profile (energy arrival process) impacts the underlying communication scheme enormously. The underlying principle behind EH based communication research is to focus on time dependent optimization of energy utilization contrast to conventional overall energy optimization for communication devices.

Fig. 2 shows a typical classification of different factors affecting EH based radio resource allocation mechanisms in wireless communication system designs. The storage structure defines the storage management system for the