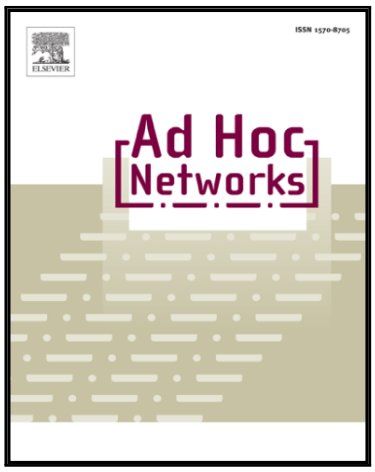

A Comprehensive Review on Energy Harvesting MAC Protocols in WSNs: Challenges and Tradeoffs

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A Comprehensive Review on Energy Harvesting MAC Protocols in WSNs: Challenges and Tradeoffs

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***Abstract*— Nowadays, wireless sensor networks (WSNs) are broadly used to set up distributed monitoring infrastructures in self-healing, self-configuring, and self-managing systems. They are composed by many elementary devices (or motes) equipped with basic sensing, computing, and communications capabilities, which interact on a collaborative basis to sense a target environment and report collected data to one or more sinks. WSNs are expected to be operational for very long periods of time, even if each mote cannot bring large energy storage units. Accordingly, Energy Harvesting mechanisms can greatly magnify the expected lifetime of WSNs. Over the years, Energy Harvesting-Wireless Sensor Networks (EH-WSN) have been thoroughly studied by the scientific and industrial communities to bridge the gap from the vision to the reality. A critical facet of EH-WSN lies in the interplay between EH techniques and MAC protocols. In fact, while EH technologies feed motes with energy, the MAC layer is responsible for a significant quota of spent energy because of message transmission/reception and channel sensing operations. In addition, the energy brought by EH technologies is not easily predictable in advance because of time-varying nature: this makes the design of the MAC protocol even more challenging. To draw a comprehensive review of the state of the art on this subject, the present manuscript first provides a detailed analysis on existing energy harvesting systems for WSNs; then it extensively illustrates pros and cons of key MAC protocols for EH-WSNs with a special focus on: fundamental techniques, evaluation approaches, and key performance indicators. Finally, it summarizes lessons learned, provides design guidelines for MAC protocols in EH-WSNs, and outlooks the impact on Internet of Things.**

Index Terms— MAC Protocols, Energy Harvested MAC, Energy Harvesting Architecture, Performance evaluation.

1. INTRODUCTION

A collection of tiny nodes capable of sensing the environment, performing simple computations and supporting wireless communications to accomplish a monitoring task can be referred to as Wireless Sensor Network (WSN). After almost a couple decades since their emergence, WSNs have been adopted in almost all possible areas including but not limited to Smart Homes [1], Smart Healthcare Systems [2,3], Intelligent Transportation Systems [4], Disaster Management Systems [5], and Continuous Video Surveillance Systems [6].

Lifetime is the Achilles' heel of WSNs: in fact, network nodes (also known as motes) are usually battery operated and spend a remarkable quota of energy to handle wireless communications primitives [7]. To avoid a frequent replenishment of batteries, it is necessary to optimize all the operations running in each single mote and quite a few approaches have been proposed so far in this direction [8-10]. Nevertheless, the experimental evidence demonstrates that WSN lifetime is never enough [7].

The bulk of proposed approaches to optimize the living time of conventional battery-powered WSNs include but not limited to energy-aware MAC protocols (SMAC [11], BMAC [12], XMAC [13]), routing and data dissemination protocols [14-16], power aware storage, duty-cycling strategies [17,18], adaptive sensing rate [19], tiered system architectures [20-22] and redundant placement of nodes [23,24].

Energy harvesting (EH) technologies [25-27] can significantly prolong WSN lifetime by converting solar, wind, vibrational, thermal or RF energy into electrical energy. Their disruptive potential has led to the formulation of the so called Energy Harvesting-Wireless Sensor Networks (EH-WSNs). The effectiveness of EH-WSNs mainly depends on the interplay between EH technologies and the protocol stack (as explained in Sec. 2).

Medium Access Control (MAC) protocol always plays a significant role in the design of WSNs as major energy consumption is due to the sensing, reception, and transmission process. Accordingly, a special attention has been paid to MAC protocol design [28-30] and a wide hierarchy of protocols has been proposed for WSNs.

With EH-WSNs, MAC design becomes even more challenging because the pattern of energy harvested from the environment is not easily predictable in advance. Although, it can be

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