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Ad Hoc Networks 4 (2006) 359–379
Ad Hoc Networks
www.elsevier.com/locate/adhoc

Energy considerations for topology-unaware TDMA MAC protocols

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Received 1 March 2004; received in revised form 27 September 2004; accepted 8 October 2004
Available online 5 November 2004

Abstract

Since the energy budget of mobile nodes is limited, the performance of a networking protocol for such users should be evaluated in terms of its energy efficiency, in addition to the more traditional metrics such as throughput. In this paper, two *topology-unaware* MAC protocols—in which the scheduling time slots are allocated irrespectively of the underline topology—are considered and their energy consumption is derived. It turns out that the *per frame power consumption* is lower for the less throughput-efficient protocol, suggesting that energy savings are achieved at the expense of throughput.

A finer energy consumption study is carried out in the sequel, focusing on the amount of energy consumed to *successfully* transmit a certain number of packets, or equivalently, on the *per successful transmission power consumption*. It is shown that the more throughput-efficient protocol consumes less energy per successful transmission under certain conditions (which are derived), due to the lower number of transmission attempts before a data packet is successfully transmitted. The same energy-efficiency relation is observed under certain conditions (which are derived) when data packets are *delay constrained* and, thus, may become *obsolete* if not transmitted successfully within a specific time interval. The conditions under which the *per successful transmission power consumption* is minimized for delay-constrained packets, are also established in this work and it is observed that when the system throughput is maximized, the power consumed is close to the minimum. Simulation results support the claims and the expectations of the aforementioned analysis.

Keywords: Power consumption; Ad-hoc; TDMA; MAC; Topology-unaware

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1570-8705/$ - see front matter
doi:10.1016/j.adhoc.2004.10.003

1. Introduction

The maximization of the *system throughput* is the main target for many Medium Access Control (MAC) protocols. In ad-hoc networks, where nodes play also the role of relays, the *network lifetime* is rather important and strongly affected by the *power consumed* by the nodes. Given the unknown, random or even changing underlying topology, the design of a MAC protocol capable of *maximizing* the system throughput and *minimizing* the *power consumption* is challenging in ad-hoc networks.

Contention-based MAC protocols are widely employed in ad-hoc networks, such as the CSMA/CA-based IEEE 802.11 [1]. In addition to the carrier sensing mechanism, MACA [2], employs the *Ready-To-Send/Clear-To-Send* (RTS/CTS) handshake mechanism. This mechanism is mainly introduced to avoid the *hidden/exposed terminal* problem, which causes significant performance degradation in ad-hoc networks. Other protocols based on variations of the RTS/CTS mechanism have been proposed as well [3–5]. TDMA-based MAC protocols have also been employed [6–11], where each node is allowed to transmit during a specific set of TDMA *scheduling time slots*. In general, optimal solutions to the problem of time slot assignment often result in NP-hard problems [12,13], which are similar to the *n*-coloring problem in graph theory.

Topology-unaware scheduling schemes assign the scheduling time slots to nodes irrespectively of the underlying topology. In [14,15], a TDMA-based topology-unaware scheme was proposed guaranteeing that at least one time slot in a frame would be collision-free. In [16], the policy in [14,15]—which does not allow nodes to access slots other than those assigned to them (referred to as the *Deterministic Policy*)—is extended by allowing access to non-assigned slots with some nonzero probability p (referred to as the *Probabilistic Policy*). It was shown that the Probabilistic Policy achieves a better performance under certain conditions when the benefit of utilizing otherwise idle slots outweighs the loss due to collisions induced by the introduced control interference. The issue of the maximization of the system throughput was also addressed and simplified bounds on the value of the access probability that maximizes the system throughput were derived. Further studies [17,18] have demonstrated the advantage of the Probabilistic Policy over the Deterministic Policy regarding the utilization of *unused* time slots either under *topology control* conditions or under *non-heavy traffic* conditions.

As throughput performance may not be the only or main concern in energy-constrained ad-hoc networks, several mechanisms, algorithms and MAC protocols have been proposed that aim to reduce the power consumed for a particular transmission [19–27]. A framework for energy-efficient communications with quality of service provisioning has been recently proposed as well [28]. In this paper, the performance of the aforementioned policies is considered with respect to the consumed energy. Since, under the Probabilistic Policy, the nodes are expected to be attempting transmissions (and consume power) over non-assigned slots as well, it is conceivable that this policy is more energy demanding, despite the potentially higher throughput achieved. It is shown that on a *per frame* basis the Probabilistic Policy consumes more power than the Deterministic Policy. On the other hand, the *power consumed per successful transmission* may be smaller under the Probabilistic Policy under certain conditions that are studied here. This study also establishes the conditions under which the *power consumed per successful transmission of delay constrained packets* under the Probabilistic Policy is smaller than that under the Deterministic Policy. Finally, simulation results support the claims and the expectations of the aforementioned analysis. In accordance with the analytical results, it is also revealed the fact that the boundaries of the value of p, for which the system throughput is maximized, derived in [16], determine a range of values of p for which the power consumed under the Probabilistic Policy is smaller than the value consumed under the Deterministic Policy. In addition, it is shown that the aforementioned lower bound of the access probability p, is close to that value of p that minimizes the power consumption.

In Section 2, a description of the system and the policies is presented. In Section 3, it is shown that on a per frame basis the power consumed under the Probabilistic Policy is higher than the power consumed