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Distributed Priority Scheduling and Medium Access in Ad Hoc Networks *

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Abstract. Providing Quality-of-Service in random access multi-hop wireless networks requires support from both medium access and packet scheduling algorithms. However, due to the distributed nature of ad hoc networks, nodes may not be able to determine the next packet that would be transmitted in a (hypothetical) centralized and ideal dynamic priority scheduler. In this paper, we develop two mechanisms for QoS communication in multi-hop wireless networks. First, we devise *distributed priority scheduling*, a technique that piggybacks the priority tag of a node's head-of-line packet onto handshake and data packets; e.g., RTS/DATA packets in IEEE 802.11. By monitoring transmitted packets, each node maintains a scheduling table which is used to assess the node's priority level relative to other nodes. We then incorporate this scheduling table into existing IEEE 802.11 priority backoff schemes to approximate the idealized schedule. Second, we observe that congestion, link errors, and the random nature of medium access prohibit an exact realization of the ideal schedule. Consequently, we devise a scheduling scheme termed *multi-hop coordination* so that downstream nodes can increase a packet's relative priority to make up for excessive delays incurred upstream. We next develop a simple analytical model to quantitatively explore these two mechanisms. In the former case, we study the impact of the probability of overhearing another packet's priority index on the scheme's ability to achieve the ideal schedule. In the latter case, we explore the role of multi-hop coordination in increasing the probability that a packet satisfies its end-to-end QoS target. Finally, we perform a set of *ns*-2 simulations to study the scheme's performance under more realistic conditions.

Keywords: distributed scheduling, medium access, IEEE 802.11, ad hoc networks

1. Introduction

Supporting real-time flows with delay and throughput constraints is an important challenge for future wireless networks. Indeed, providing differentiated quality-of-service levels increases a system's total utility when applications have diverse performance requirements, e.g., some preferring low delay, others high throughput, and others merely best effort service [18]. Consequently, both medium access control and network-layer scheduling algorithms must select and transmit packets in accordance with their QoS requirements.

In wireless networks with base stations, the base station acts as a centralization point for arbitration of such QoS demands. For example, suppose the goal is to support delay-sensitive traffic using the Earliest Deadline First (EDF) service discipline. In this case, each packet has a priority index given by its arrival time plus its delay bound. Consequently, the base station can simply select the packet with the smallest priority index for transmission on the down-link, subject to its channel being sufficiently error-free. In this way, an "ideal" EDF schedule could be approximated to the largest extent possible allowed by the error-prone wireless link.

However, in networks without base stations, there is no centralized controller which can assess the relative priorities of packets contending for the medium. Consequently, the node actually possessing the highest priority packet is unaware that this is the case; nor are other nodes with lower priority packets aware that they should defer access. Moreover, in *multi-hop* (or ad hoc) networks in which packets are forwarded across multiple broadcast regions, it becomes increasingly challenging to satisfy a flow's end-to-end QoS target.

In this paper, we introduce a new framework for dynamic priority packet transmission in multi-hop wireless networks. Our key insight is that the broadcast nature of the wireless medium together with the store-and-forward nature of multi-hop networks provide opportunities to communicate and coordinate priority information among nodes. Our goal is to exploit these system attributes and develop integrated medium access and scheduling algorithms that satisfy a high fraction of QoS targets using fully distributed mechanisms.

Our contribution is twofold. First, within a broadcast region, we devise a mechanism termed *distributed priority scheduling* in which each node locally constructs a scheduling table based on overheard information, and incorporates its estimate of its relative priority into medium access control. In

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