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Distributed Opportunistic Scheduling with QoS Constraints for Wireless Networks with Hybrid Links

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***Abstract*—Opportunistic scheduling for a wireless network with hybrid links is studied in this paper. Specifically, two link types are considered: a link of the first type always has a much lower transmission rate than a link of the second type. To avoid starvation in the first type of links, two link types must be treated differently in opportunistic scheduling, and quality of service (QoS) constraints such as maximum delay or minimum throughput must be imposed on the first link type. Considering QoS constraints, a distributed opportunistic scheduling scheme is derived based on the optimal stopping theory. Two scenarios are considered for the QoS-oriented opportunistic scheduling scheme. In the first scenario, all links within the same link type follow the same rate distribution. Thus, QoS constraints are imposed on the entire link type. In the second scenario, links of the first type follow heterogeneous rate distributions. Thus, QoS requirements need to be imposed on links with the worst performance. Performance results show that the new opportunistic scheduling scheme outperforms the existing ones in most scenarios.**

***Index Terms*—distributed opportunistic scheduling, quality of service, hybrid links, optimal stopping theory.**

I. Introduction

It is common that wireless links in a network have heterogeneous characteristics such as transmission rates and QoS requirements. Such links are called *hybrid links* in this paper. One factor leading to link heterogeneity involves application-specific requirements for different links. For example, some applications (e.g., control message transmissions in the smart grid or cognitive radio networks) impose a strong requirement on the security, and physical layer techniques [1], [2], [3] are applied to ensure perfect secrecy in corresponding links (called *secure links*) [4], [5]. Since perfect secrecy comes at the cost of degrading channel capacity [6], [7], secure links have much lower transmission rates as compared to other links (called *regular links*). Due to security concern, secure links may also demand stringent QoS guarantee. For ease of explanation throughout this paper, we use *secure links* and *regular links* to represent two link types that follow significantly different rate distributions.

Packet transmissions in a network with hybrid links can be conducted in two different approaches: 1) following a pure random access medium access control (MAC) protocol; 2) based on a scheduling scheme. The former approach is simple and easy to implement, but may lead to low throughput in a network with hybrid links due to the presence of performance anomaly [8], i.e., the wireless medium is extensively occupied by low rate transmissions on secure links. Therefore, the latter approach is necessary to improve the network throughput. Among existing scheduling schemes, opportunistic scheduling is considered as the most effective to exploit fluctuations in channel conditions to produce significant throughput gains for the entire network [9], [10], [11]. The key idea of opportunistic scheduling is explained as follows: given a transmission opportunity, if a link with the highest transmission rate is selected, the maximum throughput can be achieved. Unfortunately, these opportunistic scheduling schemes rely on the existence of the central controller (e.g., the base station in cellular networks), and hence are hard to implement in ad hoc networks or wireless mesh networks, where such a central node is not readily available. To address this issue, several distributed opportunistic scheduling schemes are proposed in [12]-[13], which utilized local information to determine whether to take transmission opportunities or not. However, the quality of service (QoS) of communication links are not taken into account in these schemes. A distributed opportunistic scheduling scheme that consider the delay as a QoS metric is developed in [14] based on the scheme in [15]. However, this scheme is not applicable to hybrid links, as it cannot guarantee QoS requirements for a specific type of links (e.g., secure links) and at the same time maximize the overall throughput. So far, there is a lack of effective distributed opportunistic scheduling to support a network with hybrid links.

In order to treat hybrid links separately and also support QoS requirements of a specific type of links, a new distributed opportunistic scheduling scheme is proposed in this paper. It is developed based on the optimal stopping theory and considering two type of links: secure links and regular links. Compared with existing opportunistic scheduling schemes, the new scheduling scheme is distinct with the following features: 1) the system overall throughput is maximized under various QoS constraints of a specific link type (e.g., secure links); 2) it can be implemented as a double-threshold scheduling policy, i.e., one threshold for each link type, and then a link determines its transmission opportunity based on this threshold; 3) the rate heterogeneity among the same type of links is also taken into account to improve QoS of links with low channel quality. Simulations are carried out to evaluate the new opportunistic scheduling scheme. Performance results verify the optimality of our scheme and demonstrate that QoS of secure links can be effectively guaranteed under both

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