Media Access Control for Ad Hoc Networks with Adaptive Antenna Arrays

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Abstract. In the past several years ad hoc networking has received a lot of attention from the wireless research community and from industry. Unlike classical cellular networks where communications is highly asymmetric, ad hoc networks form when similar stations come into close proximity and spontaneously communicate. For this reason ad hoc networks must form their own infrastructure in a dynamic and distributed fashion, without any centralized coordination. The applications often quoted for ad hoc networks include combat systems, disaster area networks and campus/conference networks. As wireless communications is increasingly embedded into various objects and devices, the role of ad hoc networking is expected to expand.

Much of commercial wireless communications is predominantly omni directional. In the past decade however, adaptive antenna arrays (AAAs) have been widely studied for use in mobile applications [2–5]. Unfortunately, multiple antenna systems have only slowly found their way into commercial applications mainly due to their cost and poor support from legacy air interfaces, especially those based on frequency division duplexing. The cost of multiple antenna systems has been dropping steadily in the past few years and it is now widely anticipated that adaptive antenna arrays will eventually find use in future ad hoc networks. The potential benefits of using AAAs in ad hoc networks include increased network capacity, improved service quality, increased wireless range extension and improved low power node operation.

In this chapter, we will review much of the recent work associated with the merging of adaptive antenna arrays and ad hoc networks. Our discussion will focus on this combination from a media access control protocol viewpoint. We will focus on how these types of protocols must be changed to accommodate AAAs compared with the classical omni directional antenna case.

1 Introduction

Ad hoc networks form when nodes come within range and communicate in the absence of any fixed infrastructure [1]. The basic notion of ad hoc packet communications dates back for decades and has found its way into standards such as the IEEE 802.11 wireless local area network [8] and Bluetooth [9]. In
IEEE 802.11, stations can operate in IBSS (independent basic service set) mode, which provides for communicating without fixed infrastructure, including a mechanism for shared station power saving. Similarly the recent Bluetooth standard enables direct ad hoc communications between enabled devices, and includes basic mechanisms for node discovery, mutual co-synchronization, and piconet formation. In both these standards the usual ad hoc mode of operation involves direct communications between the source and destination nodes when they are both within range. This is to be expected in the IEEE 802.11 case since the mandate for the standard exists only up to the data link layer.

Much of the more recent work in the ad hoc networking field involves the case where the wireless coverage areas of the nodes involved do not coincide, and therefore the nodes must use multihop communications to provide full connectivity. An example of this is shown in Fig. 1. In this network, node A cannot communicate directly with node E since they are out of range. Using multihop communications however, node A's packets can reach node E via wireless relaying through neighboring nodes such as the paths shown as A-B-C-E and A-B-D-E. Multihop communications of this type obviously implies a routing function and much of the recent work on ad hoc networks deals with the design of routing algorithms that can operate in a stable fashion in the presence of time varying topologies caused by node mobility. Many ad hoc routing protocols have been proposed in the past few years [32] and are now the subject of a number of Internet Engineering Task Force (IETF) drafts.

A media access control protocol (MAC) is required to efficiently activate links in an ad hoc network. The principles of MAC protocol design using omni directional antenna transmission have been studied for many years and this is now a well understood discipline. The addition of AAAs provides stations with directional gain during both transmission and reception. This directional selectivity has the potential for reducing co-channel interference compared with